Laboratory testing and field monitoring of interlocking concrete block clogging resistant pavement for structural and hydrological design

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Abstract- **As urbanization accelerates and cities continue to expand, the demand for transportation and infrastructure has grown significantly. However, this rapid development has also resulted in adverse effects on road development, such as increased water clogging, poor drainage, declining infiltration rates, and deplete groundwater resources, drinking water scarcity has become a major concern. A modification of traditional preamble flexible pavement comes up as a solution that has emerged in the form of interlocking concrete block clogging-resistant pavement, which can offer a more sustainable alternative to traditional pavements made of permeable or impervious concrete. By incorporating a clogging-resistant layer to enhance the previous concrete layer design, interlocking concrete block permeable pavement provides improved water management and transportation infrastructure. This innovation can reduce water clogging, enhances drainage, and can maintain groundwater tables and infiltration rates, thus providing a more sustainable approach to urban road development. In the present investigation, study of compressive strength testing and permeability test through rainfall simulator under controlled condition for different concrete mix designs of self-compacting concrete and traditional previous concrete was carried out.**

Index Terms- **Flexible Pavement, Clogging Resistant Pavement**

I.INTRODUCTION

Permeable concrete is a porous surface which allows water to percolate in the system and slowly allows it to infiltrate into soil [8]. According to David K. Hein and Lori Schaus, " Permeable pavement enables the use of a traditional source of stormwater problems as a way to both detain and "clean stormwater.". They also noted, “Permeable pavements typically consist of pervious concrete, porous asphalt, or permeable interlocking concrete block paving units over an open grade base/subbase layer(s)."[5] Despite this, low strength and water clogging issues have made maintenance costly and reduced the pavement's lifespan. Although an attempt to install it under interlocking concrete blocks was made. Permeable pavements are typically made up of pervious concrete, porous asphalt, Permeable low-density cellular concrete, Seashell Concrete, Crushed Ceramic Replacement of Coarse Aggregate, or permeable interlocking concrete block paving units over an open grade base/subbase layer(s) [6] [7] [10] [11]. Mingjing Fang, Xiao Wang, Jianjun Liu, Zhouying Xu, Yiming Chen have noted that the pavement having stretcher bond in concrete block shows more permeability. [4].

Alalea Kia, Jasmine M. Delens, Hong S. Wong, and Christopher R. Cheeseman developed a high-strength clogging-resistant pavement to address these issues [1]. T. Lucke, S. Beecham have also studied permeability of permeable pavement with two different slopes of 5% and 10% which have given them quite different infiltration behavior [9], we have done our calculation with no slope. Effect of different sediments on clogging of conventional permeable concrete was investigated by A. Kia, H. S. Wong, C. R. Cheeseman. They have found that Lower porosity samples had a greater loss in permeability due to smaller pore size, higher tortuosity and paste drain down that trap’s particles. Complete clogging occurred after 3 to 8 cycles, depending on sample porosity and exposure method [12]. Interlocking concrete block permeable pavement (ICBPP) has been increasingly used as an alternative to traditional pavement systems, but it also has its own drawbacks such as water clogging and low strength, to address this issue, the previous concrete layer was replaced with clogging-resistant pavement.

This study aims to evaluate the performance of a new pavement on the basis of structural and hydrological design. This new pavement, known as Interlocking Concrete Block Clogging Resistant Pavement (ICBCRP), has advanced structural and hydrological performance. The structural design of ICBCRP, laboratory tests were conducted to evaluate its compressive strength of Clogging Resistant Layer for M50, M30 and M20 concrete mix design with and without concrete having 12% and 13%, also pervious concrete mix of M20 having void ratio of 17.5%. For the hydrological design aspect, field monitoring was conducted to evaluate the infiltration and runoff performance of ICBCRP for 12% and 13%, pervious concrete 17.5%. The results showed that ICBPP had a higher infiltration rate compared to traditional pavement systems, potentially reducing stormwater runoff and improving water quality.

II. METHODOLOGY

The proposed methodology consists of structural and hydrological design of flexible pavement. In this methodology, interlocking permeable concrete block pavement is introduced with Clogging Resistant Layer. Calculation for the thickness of clogging resistant layer and foundation layer Alalea Kia, Jasmine M. Delens, Hong S. Wong, and Christopher R. Cheeseman has given by design formula Eqs. (1) and Eqs. (2) [1]. For ICBCRP, permeability testing was done by the similar method which was used by researchers Tameem Mohammed Hashim, Mohammed Zuhear Al-Mulali, Fatimah Fahem Al-Khafaji, Ali Abdul Ameer Alwash, Yasar Ameer Ali [2].

Design of interlocking concrete block clogging resistant pavement:

I. Structural design:

Foundation:

The main purpose of foundation is to provide required support to the above pavement to withstand the applied load. For the design of structural and hydrological was proposed by Alalea Kia, Jasmine M. Delens, Hong S. Wong, Christopher R. Cheeseman. The foundation is made up of soil subgrade and subgrade improvement layer. The support required by the foundation is completely dependent on the stiffness (surface modulus, E) of the subgrade soil. The surface modulus was calculated by $E = 17.6\ (CBR)^{0.64}$, where CBR is California Bearing Ratio either obtained by in-situ testing (BS 1377-4:1990) or taken according to the foundation class as defined in LR 1132. The foundation is then designed according to its surface modulus and foundation class as per table no. 3.7 od CD 225. To achieve design safe, the sub-base and capping layer stiffness is deducted to 60%. Depending on the foundation class, CRB and subgrade surface modulus, the thickness of the foundation layer is determined according to Section 4, Annex A of IAN 73/06 Revision 1 or Figure 1-7 in Annex A of CD 225 [13]. The minimum necessary for a foundation operating as a working platform for construction can be determined by applying Equations 2 and 3 in Annex C of LR1132. [1] [16].

Pavement thickness:

The comparatively low applied loads for footpaths and/or cycleways necessitate the use of unreinforced pavement. Based on the recommended dimensions compiled in Table 3.18 of CD 239, their design thicknesses are chosen [17]. Pavements made of rigid concrete that is intended for automotive traffic can be joined, continuously reinforced, or unreinforced. On the basis of the concrete's flexural strength, Fig. 2.26 of CD 226 can be used to calculate the thickness of continuously reinforced concrete pavement [18]. The thickness of jointed unreinforced concrete pavements can be calculated using Equation 1, which is based on over 30 years of experimental data from concrete roadways [1].

$$\mathrm{Ln}(\mathrm{H}_p) = \frac{\mathrm{Ln(T)} - 3.466\ \mathrm{Ln(Rc)} - 0.4836\ \mathrm{Ln(E)} + 40.78}{5.094} \quad (1)$$

Where, Hp is the thickness of the unreinforced concrete slab (in millimeters), T stands for the design cumulative traffic load (msa), R is the reinforcement cross-sectional area per meter width of the slab (mm^2 /m), E is the foundation stiffness (MPa) connected to foundation class, and R_c is the 28 days mean concrete strength (MPa). When using the mean annual frost index (MAFI) to evaluate if a subgrade is sensitive to frost, special considerations must be made. The thickness of the rigid pavement system should exceed 350 mm for MAFI < 50 mm, else it should exceed 450 mm for MAFI ≥ 50 mm [17].

II. Hydrological design:

Infiltration system

The sub-base depth determination is a crucial part of the hydrological design of permeable concrete pavements. This is determined by the amount of storage space needed to guarantee that surface flooding won't occur and the maximum depth of water held (h_{max}) doesn't surpass the pavement. The amount of rainfall, the peak surface runoff from nearby places, and the permeability values of the pavement, sub-base, and underlying soil all affect the sub-base's depth. The method for estimating h_{max} is dependent on the three different types of site characteristics and infiltration systems: There are three possibilities: A) complete infiltration of rainfall into the underlying soil; B) partial infiltration; and C) no infiltration of rainwater into the underlying soil. There are two conditions that must be met for the use of a Type A infiltration system: (i) the subgrade infiltration rate must be between 1×10^{-3} and 1×10^{-6} m/s, and (ii) there must be at least one meter of space between the base of the subgrade improvement layer and the water table in order to ensure adequate storage depth and prevent flooding [19]. As a result, the design methodology in this paper is based on Type A infiltration and follows a plane infiltration procedure for flat pavements. The minimum needed thickness of the sub-base (H_f) is determined by h_{max} using Eqs. 2 and 3. To make sure that the time it takes for the system to empty (discharge) is no more than 24 hours, Eq. 3 is employed [20].

$$h_{\max} = \frac{\mathrm{D\ (R\ i - q)}}{\mathrm{n}} \quad (2)$$

$$t_{1/2} = \frac{(\mathrm{n} \times \mathrm{hmax})}{2\ \mathrm{q}} \quad (3)$$

Where D is the amount of time the rain event lasted (in hours), i is the intensity of the rain (in millimeters per hour), q is the infiltration rate (in millimeters per hour) of the underlying soil as determined by site testing and taking into account the factor of safety form SuDS Manual depending on the size of the permeable pavement, R is the ratio of the pavement catchment area to the size of the permeable pavement area (≤2 for conventional permeable concrete pavements) and n is the porosity of the sub-base layer (typically 20–40 %) [19] [21].

Design of interlocking concrete block pervious concrete pavement:

Thickness of layer other than pervious layer was design according to the Table 1 Design Catalogue for Pavement Thickness from IRC: SP: 63-2018 [18]. The Pervious layer thickness was taken same as Clogging Resistant layer so as to preform comparative study of both the pavement.

Sample preparation for compressive testing was done, and also for permeability test which was performed using a rainy simulator. For compressive testing, thirteen different samples are tested, under clogging resistant pavement six samples of M20, M30, and M50 in combination with admixture (0.2%) and without admixture, having two different porosities of 12% and 13%. In previous concrete pavement, samples of M20 having void content of 17.25% are carried out. For the permeability test, we tested a sample of M20 having a porosity of 12%, 13% and previous concrete of void content 17.5%.

III.SAMPLE PREPARATION

Compressive Testing:

The preparation of samples with a target porosity range of 12% and 13%. The sample was created by incorporating wooden sticks of varying diameters (2 to 3 mm) using a self-compacting mortar. The mortar was composed of M53 grade and fine-grained river sand. The sand had a specific gravity of 2.64 and a 24-hour absorption of 1%. To achieve the desired workability, a polycarboxylic-ether type superplasticizer added at 0.2% was used. Steel molds were used to cast the samples using 75 × 75 × 75 mm cubes with the wooden sticks held in place using two cardboard pieces with holes to accommodate the sticks fixed at the top of the molds. In total, 72 samples were prepared using this approach. For testing purposes, the part of the wooden sticks was removed from the surface of the cubes.

Pervious Concrete Pavement:

The preparation of pervious concrete with a target porosity of 17.5%. The previous concrete was prepared without fine aggregate. The concrete of M53 grade and coarse aggregate of 9.5 mm were used. Six samples were prepared to test at 7-day and 28-day strength.

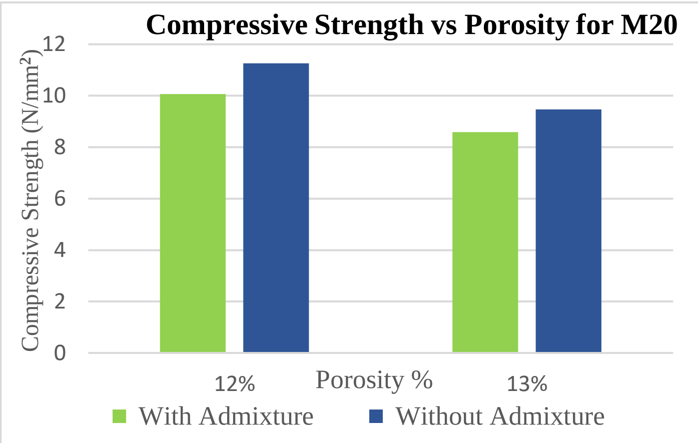
ICBCRP:

The preparation of three samples of 50 x 10 x 10 cm and one sample of 30 x 10 x 10 cm having overall 44 pores with a diameter of 2.5 cm to achieve the porosity of 12 % and for 13% overall pores where 48 with a diameter of 2.5 cm. These sample sizes were decided according to the dimension of tank in with permeability test was performed.

IV. RESULT AND DISCUSSION

Comparison of Graph of Compressive Strength test: -

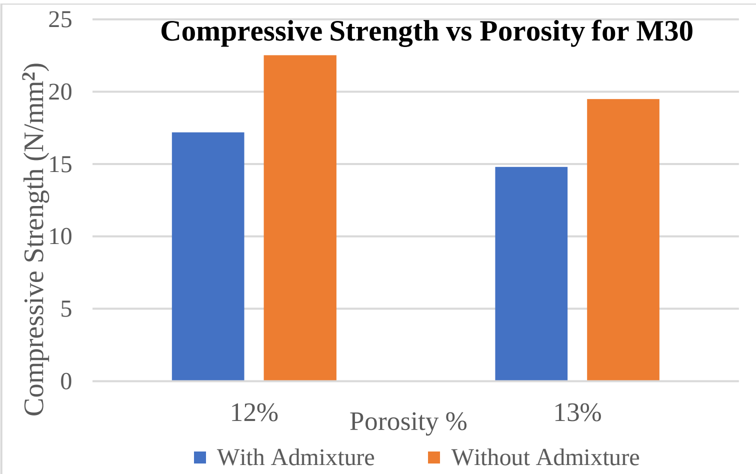
Porosity-Compressive Strength Relationship in M20 Grade Concrete with and without Admixture:



Graph No 1: Porosity-Compressive Strength Relationship in M20 Grade Concrete with and without Admixture

Graph No. 1 show that porosity of the concrete increases, the compressive strength decreases. This relationship is observed in both cases, with and without the admixture. However, the use of an admixture seems to have a negative impact on the compressive strength of the concrete.

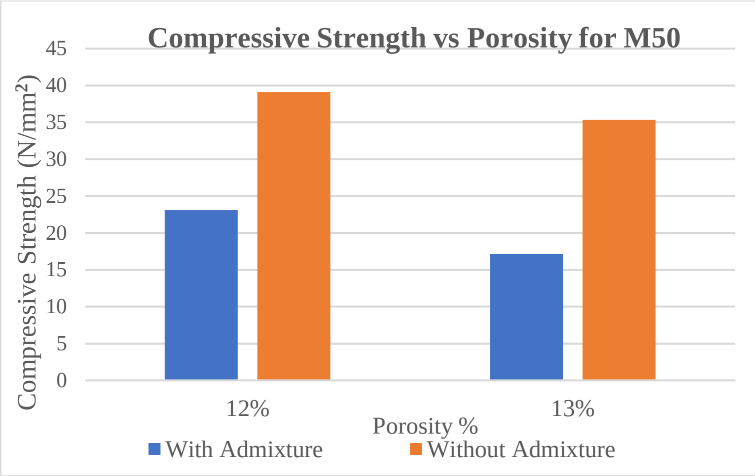
Porosity-Compressive Strength Relationship in M30 Grade Concrete with and without Admixture:



Graph No 2: Porosity-Compressive Strength Relationship in M30 Grade Concrete with and without Admixture

Graph No. 2 indicates that as the porosity of the concrete increases, the compressive strength decreases. This relationship is observed in both cases, with and without the admixture.

Porosity-Compressive Strength Relationship in M50 Grade Concrete with and without Admixture:



Graph No 3: Porosity-Compressive Strength Relationship in M50 Grade Concrete with and without Admixture

Graph No. 3 indicates that as the porosity of the concrete increases, the compressive strength decreases. This relationship is observed in both cases, with and without the admixture.

Comparing Compressive Strength of M20, M30, and M50 Grades of Concrete with and without Admixture at Different Porosity Levels:

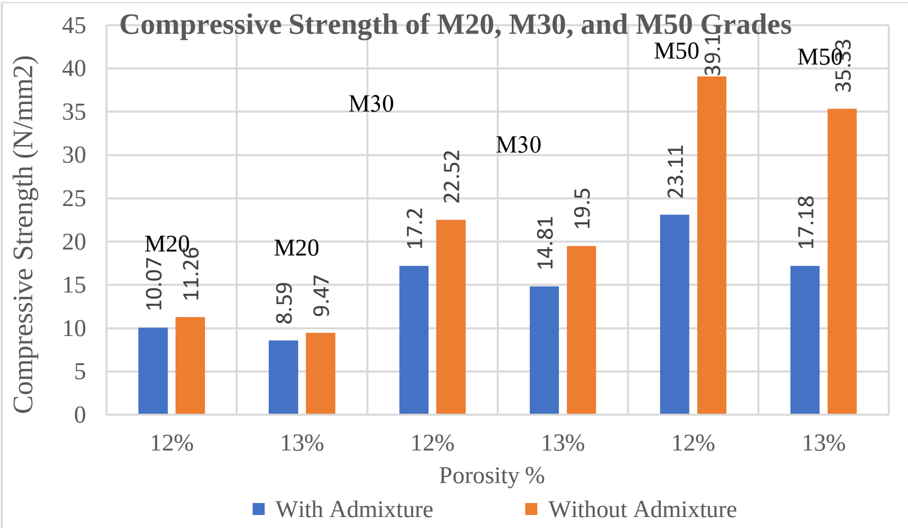
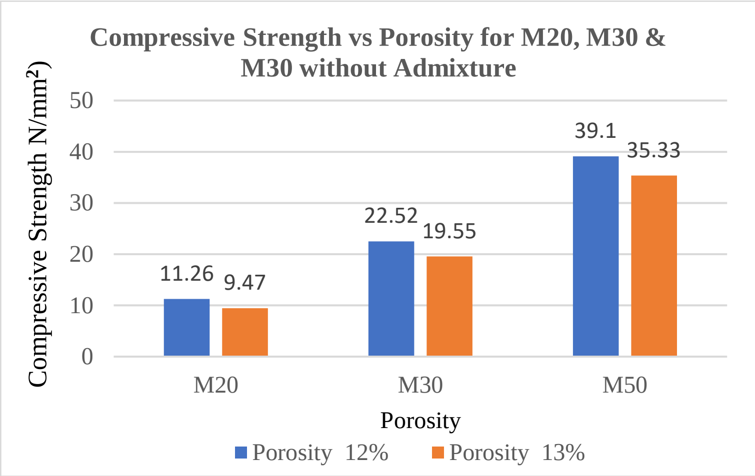


Fig No 4: Comparing Compressive Strength of M20, M30, and M50 Grades of Concrete with and without Admixture at Different Porosity Levels

Graph No. 4 represents the compressive strength of concrete at two different levels of porosity, 12% and 13%, for three different grades M20, M30, and M50 with and without the use of an admixture. Based on the testing, it is evident that the use of an admixture generally leads to lower compressive strength compared to concrete without it, across all grades and porosity levels. Furthermore, the difference in compressive strength between concrete with and without admixture is more noticeable at higher grades (M50) than at lower grades (M20).

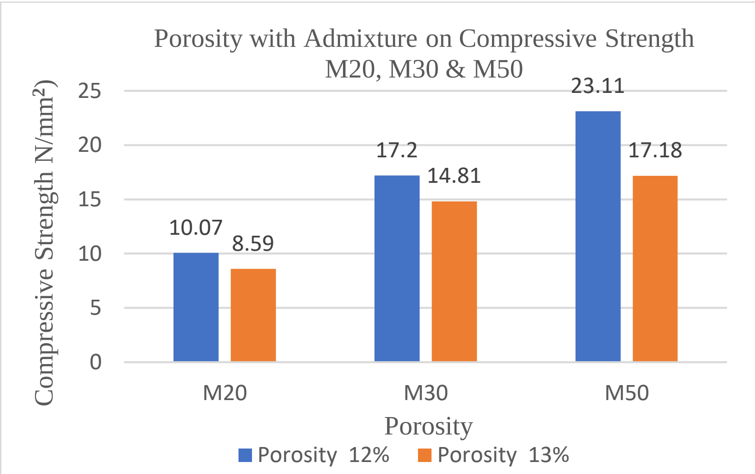
Comparing Compressive Strength of M20, M30, and M50 Grades of Concrete without Admixture at Different Porosity Levels:



Graph No 5: Comparing Compressive Strength of M20, M30, and M50 Grades of Concrete without Admixture at Different Porosity level

Graph No. 5, depicts the compressive strength of three different concrete mixes - M20, M30, and M50 - without the addition of an admixture at various levels of porosity. It can be observed that the compressive strength of concrete increases as the porosity level decreases for all three mixes. Furthermore, it is evident from the data that the concrete mix M50 exhibits the highest compressive strength at all porosity levels, followed by M30 and M20, respectively. This trend suggests that concrete mixes with higher grades exhibit better compressive strength than those with lower grades.

Effect of Porosity with Admixture on Compressive Strength of Concrete Mixes M20, M30, and M50:

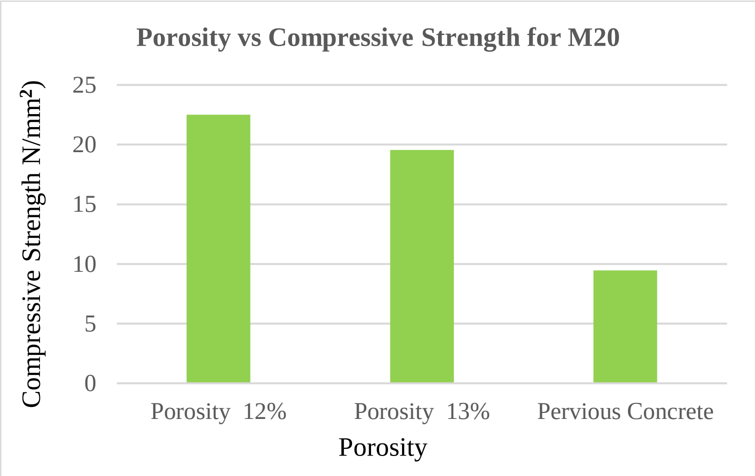


Graph No 6: Effect of Porosity and Admixture on Compressive Strength of Concrete Mixes M20, M30, and M50.

Graph No. 6 depicts the compressive strength of concrete mixes with different porosity levels and an admixture, for three different grades of concrete - M20, M30, and M50. The data shows that as the porosity level increases, the compressive strength of the concrete decreases. This is due to the presence of voids in the concrete which weakens its overall strength.

However, the higher-grade concrete mixes, M30 and M50, show a smaller decrease in compressive strength with increasing porosity levels, indicating that they are more resilient to higher porosity levels. Additionally, the use of an admixture appears to improve the compressive strength of all three grades of concrete mixes, regardless of the porosity level.

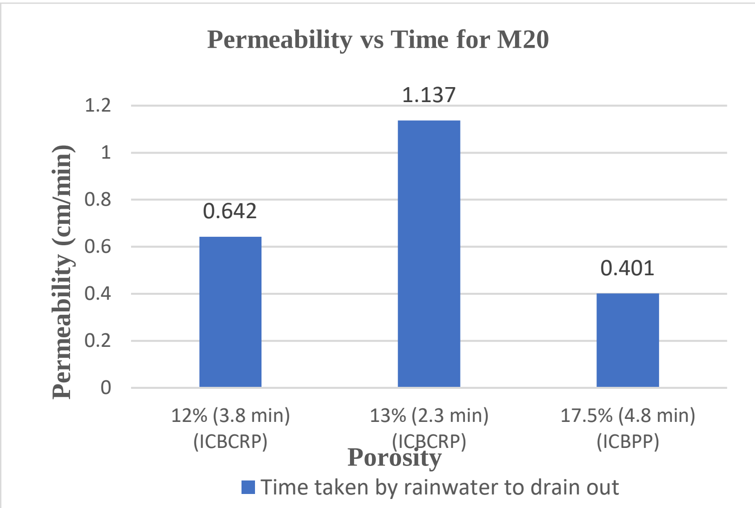
Effect of Porosity on Compressive Strength of M20 Grade Concrete with and without Admixture:



Graph No 7: Effect of Porosity on Compressive Strength of M20 Grade Concrete with and without Admixture

The above graph no. 7 illustrates the compressive strength of M20 grade concrete at varying levels of porosity, as well as the strength of pervious concrete without an admixture. The data reveals that the compressive strength of M20 concrete decreases as the porosity level increases. This is evidenced by the lower compressive strength values observed at 13% porosity, in comparison to 12% porosity.

Comparison Graphs for Permeability Test: -
Permeability time Graph: -



Graph No 8: Comparison Graphs for Permeability test Time taken by rainwater to drain out

Graph No. 8 illustrates the permeability of porosity 12%, 13% for ICBCRP and void ratio of 17.5 % for ICBPP. It shows that as the porosity increases the permeability is increasing for ICBCRP. Whereas in ICBPP void ratio is more than ICBCRP, permeability is less.

V.CONCLUSION

A new type of permeable pavement which is clogging resistant, yet achieves high permeability has been studied. This permeable flexible pavement was tested against conventional previous pavement for compressive testing and permeability testing.

1. The observation relieves that self-compacting mortar was used where we have changed the proportion of w/c ratio which was increased by 0.1% and admixture content was decreased by 0.05% which haven't work out, had given lower compressive strength.
2. It was also observed that the compressive strength is decreasing as the porosity level increases from 12% to 13%, indicates that increase in porosity lead to decreases in strength.
3. The permeability is observed more in ICBCRP than in ICBPP for 12% porosity 40%, and for 13% porosity 65% higher permeability rate was observed.
4. The time taken by rainwater to drain out was for ICBPP 50% higher than 13% porous ICBCRP, whereas in 12% porous ICBCRP 30% higher time was recorded.
5. The compressive strength of concrete mixes without any admixtures was tested for three different mixes, M50, M30, and M20, at porosity levels of both 12% and 13%. Results revealed that for mixes with 12% porosity, M20 had a compressive strength 70%

lower than M50, and M30 had a compressive strength 40% lower than M50. Similarly, for mixes with 13% porosity, M20 had a compressive strength 75% lower than M50, and M30 had a compressive strength 45% lower than M50.

6. The compressive strength of concrete mixes with admixture was tested for three different mixes: M20, M30, and M50, and the results were analyzed. It was found that for both sets of tests, M20 had the lowest compressive strength, with values 60% and 50% lower than M50 for the first and second tests, respectively. Similarly, M30 had a lower compressive strength than M50, with values 25% and 20% lower than M50 for the first and second tests, respectively.

REFERENCES:

1. Alalea Kia, Jasmine M. Delens, Hong S. Wong, Christopher R. Cheeseman, "Structural and hydrological design of permeable concrete pavements", Case Studies in Construction Materials, 2021.
2. Tameem Mohammed Hashim, Mohammed Zuhear Al-Mulali, Fatimah Fahem Al-Khafaji, Ali Abdul Ameer Alwash, Yasar Ameer Ali, "An Experimental comparison between different types of surface patterns of permeable interlocking concrete pavement for roadway subsurface drainage", Case Studies in Construction Materials" 9th June 2022.
3. Alalea Kia, Hong S. Wong, Christopher R. Cheeseman, "High-strength clogging resistant permeable pavement", International Journal of Pavement Engineering, April 2019.
4. Mingjing Fang, Xiao Wang, Jianjun Liu, Zhouying Xu, Yiming Chen, "Design, application and performance improvement of Eco-Permeable pavement materials (Eco-PPMs): A review", Construction and Building Materials, 360 (2022), pg no 129.
5. David K. Hein and David R. Smith, ''Development of an ASCE Standard for permeable interlocking concrete pavement'' Technical Direction, interlocking concrete pavement Institute ,13921 park center Road, October 2015.
6. Dina M. Sadek, Hanan A. El Nouhy, "Properties of paving units incorporating crushed ceramic", Housing and Building National Research Center HBRC Journal, vol 10, (2014), 198–205
7. Sundeep Inti, Thomas W. Evans III, Michael Flores, Jayraj Singh Solanki, Chandramouli V. Chandramouli "Permeable low-density cellular concrete (PLDCC) as a replacement for aggregate layers in permeable parking lots", Developments in the Built Environment, vol 8, September 2021.
8. Fatma Aşilioğlu, "Permeable Pavements for Pedestrian Use", Landscape and Ornamental Plants Program, Kalecik Vocational School, Ankara University, vol 08, 2015.
9. T. Lucke, S. Beecham, "An investigation into the differences in infiltration capacity between porous and permeable concrete pavers installed on sloping sub-catchments", HAL Open Science, Page No 3-6.
10. Monita Olivia, ''Mechanical properties of seashell concrete" Procedia Engineering 125 (2015) 760 – 764 (2015).
11. Mohamed Boutouil, Nassim Sebaibi, Dang Hanh, Nguyen "Valorization of seashell by-products in previous concrete pavers". Elsevier, Page no. 152-160.
12. Kia, H. S. Wong, C. R. Cheeseman, "Development of clogging resistant permeable concrete.", Research Gate, September 2018.
13. Design Manual for Roads and Bridges - Pavement Design CD 225 Design for New Pavement Foundations Revision 1, Highways England, London, United Kingdom, 2020.
14. Concrete Mix Proportioning - Guidelines Second Revision, Cement and Concrete Sectional Committee, CED 02, Manak Bhavan, 9 Bahadur Shah Zafar Marg New Delhi-110002, January 2019.
15. Guidelines For the Use of Interlocking Concrete Block Pavement First Revision, Indian Roads Congress Kama Koti Marg, Sector-6, R.K. Puram, New Delhi-110 022 November, 2018.
16. W.D. Powell, J.F. Potter, H.C. Mayhew, M.E. Nunn, The Structural Design of Bituminous Roads, Transport and Road Research Laboratory (TRL), Crowthorne, Berkshire, 1984. Report No.: LR1132.
17. Design Manual for Roads and Bridges - Pavement Design CD 239 Footway and Cycleway Pavement Design Revision 1, Highways England, London, United Kingdom, 2020.
18. Highways England, Design Manual for Roads and Bridges - Pavement Design CD 226 Design for New Pavement Construction Revision 0, Highways England, London, United Kingdom, 2020, pp. 1–73.
19. The SuDS Manual, Technical Guidance on Sustainable Drainage Systems, The SuDS Manual, London, United Kingdom, 2015, pg. 1968.
20. CIRIA C582, Source Control Using Construction Pervious Surfaces, CIRIA, London, United Kingdom, 2002, pp. 1–152.
21. CIRIA R156, Infiltration Drainage - Manual of Good Practice, CIRIA, London, United Kingdom, 1996, pp. 1–107.
22. IRC: SP: 63-2018 – "Guidelines for the use of Interlocking Concrete Block Pavement"