International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 3, May-June 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Studies on Effect of Elevated Temperature on Porosity Concrete

Mahadeva C K[1], Dr. Mahesh Prabhu K[2]
[1]Research Scholar, GEC Ramanagara
[2]Associate Professor, GEC Ramanagara
Dept. of Civil Engineering, Government Engineering College, Karnataka, India

------------------------------------*************************--------------------------------

Abstract:
Porosity in concrete is the important parameter to evaluate the structural parameters in different types of concrete like geo-polymer concrete, porous concrete and structural concrete. Porosity gives on information about engineering properties like voids, permeability, rate of flow, length and size of the pores.
Above mentioned properties are important to know the drainage properties as well as compressive strength of concrete. Porosity can be defined as air-filled or empty spaces inside the concrete; some of these voids are connected or disconnected in the concrete.

Keywords — **Porosity, Temperature, Gel space**

------------------------------------*************************--------------------------------

1. INTRODUCTION
Porosity in concrete is the important parameter to evaluate the structural parameters in different types of concrete like geo-polymer concrete, porous concrete and structural concrete. Porosity gives on information about engineering properties like voids, permeability, rate of flow, length and size of the pores.
Above mentioned properties are important to know the drainage properties as well as compressive strength of concrete. Porosity can be defined as air-filled or empty spaces inside the concrete; some of these voids are connected or disconnected in the concrete. Number and size of the porosity is more in a concrete that reduces the strength and increases the permeability characteristics in concrete.
Porosity in structural concrete is mainly effect on tension properties of steel and compressive strength in structural concrete. When the concrete subjected to high temperature it leads to thermo mechanical properties of concrete like stress distribution and cracking in concrete. The most important effect of elevated temperature on concrete is dehydration of cement paste and thermal cracking due to incompatibility. Concrete having a voids means it is not durable and strong. [1]

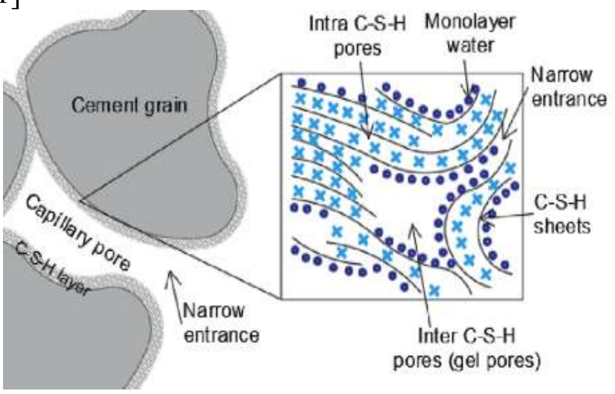

Fig:01 Pore structure diagram

Figure 01 shows the pore structure characteristics of cement paste and gel paste.
Porosity in concrete is influenced to crack development in hardened concrete.
Porosity is developed in both fresh concrete and hardend concrete has influence on the properties in many aspects.
In the case of fresh concrete porosity is developed from the following circumstances

1. At the time of casting
2. Reaction occur's in between aggregates and cement paste

In case hardened concrete porosity can be evaluated due to bonding inbetween aggregates and cement paste. Hence porosity is occurs in all varities of concrete used in the construction of civil engineering structures.

Porosity is there in concrete that will influenced to lowering the density of concrete as well as the strength of the concrete.porosity leads to drainage properties of paved concrete to drain out og runnung water.

Porosity is measured the volume of voids in concrete.

Voids are formed in concrete due to inadequate bondage between the fine, coarse aggregate and cement paste.

Bondage between fine and coarse aggregates are mainly depends on the water cement ratio as well as cement content in a mix. Development pores in a varities of concrete from different varieties of coarse aggregates like size and shape of that aggregates. Porosity either it may air filled voids, empty voids and water filled gaps.

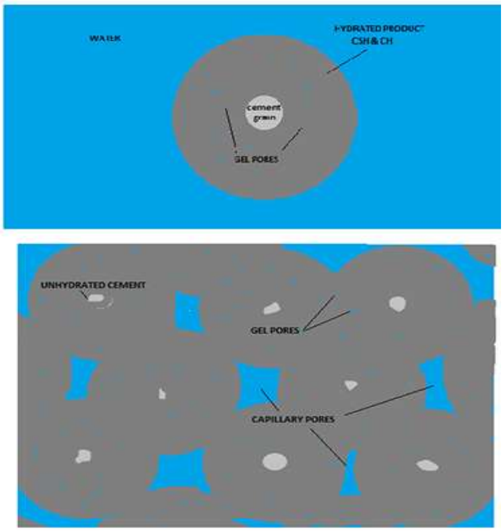

Fig: 02 Development of gel pores and capillary pores in cement paste

Pores in a concrete generally classified into two categaries

Based on the size of the pores.

1. Gel pores (<10nm)
2. Capillary pores (10nm -100000nm) [1]

Generally smaller water filled pores are categarised as the gel pores but in the capillary pores size of the water filled pores larger than the gel pore and gel pores contain large evaporated water as show in the figure 2.

Excess water within the w/c ratio is the primarily influencer in porosity. As a result, there are lower strengths and higher permeability with higher w/c ratios. Permeability, meanwhile, affects concrete durability and serves as the link between w/c ratio and durability

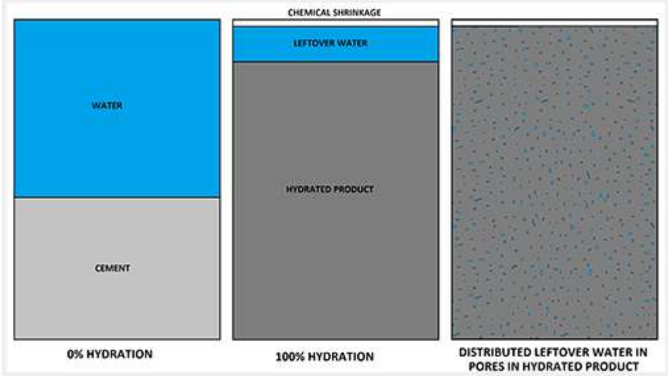

Fig:03 Hydration with water filled pores diagram

2. SURVEY OF THE FACTOR AFFECTING POROSITY OF CONCRETE

2.1 Influence of Pore Structure Characteristics on the Mechanical and Durability Behavior of Pervious Concrete Material Based on Image Analysis [1]

Parking lots and other lightweight streets are common places to find applications for pervious concrete. The features of the pore structure of pervious concrete have a significant impact on its performance. This study examines the connections between the pore structure properties, durability, compressive strength, porosity, and permeability of pervious concrete. There is additional discussion of the effects of fine aggregate and basalt fiber on pervious concrete. A variety of pore architectures were achieved in the specimens of pervious concrete by varying the proportions of basalt aggregate sized between 5 and 10 mm and 10 and 15 mm. Features of the pore structure, including pore distribution, pore diameters, and porosity area of the concrete.

2.1.1 Effect of aggregate on porosity

Pore size depends on percentage of aggregate used to prepare a concrete from this research paper conclude that increase the percentage of aggregate, the pore size get decreased and Also area porosity and volumetric porosity nearly equal.

2.1.2 Effect of fibers on porosity concrete

When fibers used in concrete reduces the porosity of concrete

Volumetric porosity of concrete slightly changes when fibers used in concrete.

2.1.3 Test involved

2.1.3.1 Volumetric porosity test

2.1.3.2 Permeability Test

2.1.3.3 Compression Test

2.1.3.4 Durability Test

2.1.3.1 Volumetric Porosity Test

Indian standard codal reference: **IS-1528**

Volumetric porosity of the concrete can be calculated by using the equation

P= [1-((m1-m2)/V*ρw) x100]

Where,

P= Volumetric porosity

m1= mass of the oven dried sample in kg

m2= mass of the saturated sample in water in kg

V= volume of the specimen in m3

ρw = Density of water in kg/m3

The porosity of concrete has influence on the properties in many aspects. Composition of concrete, casting in practice, maturing and hardening, cement reactions and risks at freezing, all are influenced by porosity.

2.1.3.2 Permeability Test

Indian standard codal reference: **IS-3085**

Permeability K = QL/Aht

Where,

K= Permeability coefficient mm/sec

Q = Quantity of flow water in m3/sec

L = Length of the specimen in m

A= Cross sectional area of the specimen in m2

H= Head of water in meter

2.1.3.3 Compression Test

Compressive strength of the concrete cube can be conducted and determined by using **IS-516**.

2.1.3.4 Durability Test

Durability test was conducted by using free-thaw durability test by using following formulae.

The loss rate of compressive strength was calculated by Λfc = [(fc0 – fcn)/ fc0] x100%

Where,

Λfc = is the loss rate of the compressive strength (%)

fc0 = compressive strength of the specimens

fcn = compressive strength of the freeze–thaw specimens

2.2 Experimental Study on Damage Evaluation,
Pore Structure and Impact Tensile Behavior of 10 ‑ Year ‑ Old Concrete Cores After Exposure
to High Temperatures [2]

This research paper gives the information about a new prediction tool that utilizes a machine learning framework to assess the effective porosity and compressive strength of pervious concrete material depending on its composition. The ratio of aggregate to cement, the ratio of water to cement, the minimum size of coarse aggregate, the presence of silica fume or sand, effective porosity and compressive strength. The most applicable machine learning techniques—extreme gradient boosting (XGB)—were used to train and evaluate this dataset.

2.3 The relationship between porosity and strength for porous concrete [3]

As for many porous media, the strength of porous concrete is significantly affected by the porosity of its internal structure. This paper describes the development of a mathematical model to characterize the relationship between compressive strength and porosity for porous concrete by analyzing empirical results and theoretical derivations. The suitability of existing equations for porous concrete is assessed and a new model is proposed in this research paper. The new model, which was derived from Griffith's theory. It is demonstrated that the proposed model could provide a better prediction of porous concrete compressive strength based on the material porosity.

2.4 Investigating porous concrete with improved strength: Testing at different scales [4]

In this research study gives an information about, the Porous concrete incorporates a high percentage of meso-size air voids that makes its mechanical characteristics to be different from normal concrete. A research project was undertaken to design a special type of porous concrete that fractures into small fragments when exposed to impact loading while having sufficient static strength, to be used in protective structures such as safety walls or storages for explosives. In the concretes designed, while a sufficient static strength was required, high porosity was essential to facilitate the formation of multiple cracks and the subsequent fracturing. Production of porous concretes having improved static compressive strengths was accomplished by modifying the mixture design and the compaction technique; while the design procedure was supported by macro and meso-scale mechanical testing, computed tomography, microscopy and X-ray diffraction analysis

2.5 Effect of Different Admixtures on Pore Characteristics, Permeability, Strength, and Anti-Stripping Property of Porous Concrete [5]

This researchers gives an idea to solve the problem of insufficient strength and durability of porous concrete pavement, seven different admixtures were used in this study so that the above properties could be optimized. The strengthening effect of admixtures on the strength and anti-stripping property of porous concrete was evaluated. The effects of different admixtures on the pore characteristics, strength, and anti-stripping of porous concrete were analyzed with CT tomography technology. The relationship between the pore characteristics of porous concrete and its strength, the anti-stripping property, was explored separately, and the correlation between the strength and anti-stripping property was also investigated. The addition of admixtures affected the pore characteristics of porous concrete, and there was no significant correlation between them. The strength of porous concrete was improved by the addition of admixtures, but the addition of different admixtures had different effects on the improvement of strength. Meanwhile, there was no significant correlation between the strength and pore characteristics. Adding admixtures could improve the anti-stripping property of porous concrete, however, different admixtures had different improvement effects. The effect of porosity on anti-stripping property was limited, while the pore number and equivalent aperture had no effect. There was no obvious correlation between the strength and anti-stripping property of porous concrete prepared with different admixtures.

2.6 Predicting the Compressive Strength and the Effective Porosity of Pervious Concrete Using Machine Learning Methods [6]

This paper aims to develop a novel prediction tool based on the machine learning framework to evaluate the compressive strength and effective porosity of pervious concrete material from its compositions. To address this difficult task, 14 data sources were collected from the literature to build a dataset of 164 samples. The dataset included seven mixture design features (e.g., aggregate-to-cement ratio, water-to-cement ratio, minimum coarse aggregate size, the presence of sand or silica fume, effective porosity, and the compressive strength). This dataset was trained and tested by the most relevant machine learning methods: the extreme gradient boosting method (XGB), the random forest regression method, and the support vector machine method. The Particle Swarm Optimization method was applied to tune the models' hyper parameters. It was observed that the extreme gradient boosting method significantly outperformed the accuracy of the other methods. Relatively high R-squared values of 0.92 and 0.88 were obtained for the compressive strength and effective porosity predictions. Furthermore, to account for the role of compaction, the original database was refined to obtain a 36 samples subset that considered compaction energy. Based on our assessment of this subset, results yielded superior R-squared values up to 0.99 for compressive strength, and 0.97 for effective porosity, revealing the effectiveness and accuracy of this research.

2.7 Influence of Pore Structure Characteristics on the Mechanical and Durability Behavior of Pervious Concrete Material Based on Image Analysis [7]

Pervious concrete has been widely used in parking lots and other lightweight streets. Performances of pervious concrete are strongly dependent on its pore structure characteristics. This paper investigates the relationship among porosity, permeability, compressive strength, durability and the pore structure characteristics of pervious concrete. The influences of basalt fiber and fine aggregate on the pervious concrete are also discussed. Pervious concrete specimens with different pore structures were prepared by combining basalt aggregate with size of 5–10 mm and 10–15 mm at different proportion. The pore structure characteristics such as area porosity, pore sizes, and pore distribution of pervious concrete were obtained and analyzed using image analysis method. Experimental results showed that the pore structure characteristics of pervious concrete have effects on its mechanical and durability behaviors. Homogeneous pore distribution and large distances between pores increase the compressive strength and improve freeze–thaw durability of pervious concrete. Due to the difference in the internal pore structure of pervious concretes, specimens with similar volumetric porosities had different permeability coefficients. A series of numerical models were regenerated through a MATLAB code using pore structural parameters derived from the image analysis method and then the numerical models were fed to ANSYS for meshing and further simulation. The comparison of the simulation and experimental results showed close accuracy, which verified the applied simulation analysis method based on image analysis technology.

2.8 An Experimental Investigation on Pore Structures of Pervious Concrete Using Digital Image Analysis [8]

Pervious concrete is one of the felicitous engineering tools to address the unexpected environment problems i.e. water logging, depletion of ground water table etc. However, the pore structure features (porosity, pore-sizes etc.) play a dominant role in the field of structural and functional performance of pervious concrete. But there has not any standard experimental procedure been developed yet to determine these properties precisely. With this background, this research work had been planned. The major objective of this study was to investigate the pore structures using "Digital Image Analysis". The pore structure features, such as porosity, pore size etc. are the key parameters of pervious concrete, it is indispensable to investigate these properties precisely to get better understanding about the structural and functional performance of pervious concrete. Even though, several researches had been conducted on pervious concrete in the past, these key features were not apparently determined due to the unavailability of sophisticated method. Moreover, these traditional methods are not substantial enough to investigate these properties more precisely. As a result, pervious concrete is not widely assigned in construction work in our country yet. Therefore, a novel sophisticated technique-"Digital Image Analysis" has been introduced in this study. The main objective of this study was to investigate the pore structure features of pervious concrete more precisely using "Digital Image Analysis".

3. COMMON TESTS APPLIED TO INVESTIGATE THE POROSITY OF CONCRETE

3.1. Permeability test
3.2. Compressive test
3.3. Air content test for fresh concrete
3.4. Digital Image processing technique to estimate the pore structure characteristics

3.1. Permeability test:

Permeability characteristics of concrete to be evaluate based on the guidelines specified in IS-3085. Permeability laboratory test is to be conducted to find the permeability coefficient of concrete, the permeability coefficient of concrete Also gives an idea about the amount of discharge through the concrete pores and its rate of flow.

3.2 Compressive strength

Compressive strength of the concrete cubes to be evaluate and conduct the experiment based on the guidelines given in IS-516 code book. Compressive strength of concrete is inversely proportional to permeability characteristics of the concrete. Whenever concrete cubes have more porosity then strength is automatically decrease due to fracture characteristics in concrete.

The stress carrying capacity of fully compacted concrete to be more compare to partly compacted concrete. Load distribution of aggregates and cement paste is mainly depends on pore structure characteristics of concrete.

3.3 Air content test for fresh concrete

Evaluation of air content in concrete is too important because due to percentage of air voids we need to find the pores available in the concrete structure hence we need to conduct this experiment accordance with the Indian standards.

3.4. Digital Image processing technique to estimate the pore structure characteristics

Image processing technique is helpful to evaluate morphological features and number of pore characteristics available in the concrete structure

4. CODAL RECOMMANDATIONS ON POROSITY OF CONCRETE

1. IS-3085
2. IS-1199 PART-IV
3. IS-516

5. DISCUSSION ON THE MAJOR FACTOR THAT CONTRIBUTES TO THE POROSITY OF CONCRETE AS IDENTIFIED

Porosity is developed in different categories of concrete from the following circumstances.

5.1. Inadequate water mix proportions
5.2. Different morphological properties of coarse aggregates
5.3. Air content
5.4. cement paste volume
5.5. Improper compaction
5.6. Degree of hydration [1]

5.1. Inadequate water mix proportions

Increasing water cement ratio porosity of concrete goes on increasing upto certain limit. For fixing water cement ratio for porous concrete there is no recommandations from indian standard. From trail and error method we fix the w/c ratio and from previous researchers carried out.

5.2. Different morphological properties of coarse aggregates

Based on aggregate shape it can be classified into foloowing catagaries

1. Rounded
2. Irregular
3. Flaky aggregate
4. Elongated aggregate

Above four aggregate properties influence to develop the porosity of concrete.

5.3. Air content

Entrained air disturb the distribution of pores and particle size,which may cause the significant chance in the micro structure in the hardened concrete particularly in its pore structure. This will chance to influence on porosity as well as strengty of concrete.

5.4. Cement paste volume

The porosity of cement paste depends on many factors and typically decreases with water/cement ratio and increasing curing period. Porosity also increases with curing temperature; the difference mostly concerns the volume of large pores.

5.5. Improper compaction

It is known that poor compaction results in an excessive volume of pores caused by entrapped air that is accidentally introduced in concrete during mixing and pouring. Some of these pores are typically much larger than those usually found in fully-compacted concrete and have very low capillary suction potential.

5.6. Degree of hydration

The hydration of Portland cement incorporates chemically bound water (CBW) into the structure of the formed hydrates and keeps water adsorbed on their surface, especially in calcium silicate hydrate (C-S-H). The evolution of hydration gradually reduces the porosity of the paste, keeping water remaining in the pores

CONCLUSIONS

1. Porosity of concrete mainly depends on morphological characteristics of coarse aggregate, volume of the cement paste, air content and degree of hydration.
2. Porosity of concrete effects on flow properties as well as strength properties of concrete.
3. Size and number of pores is mainly depends on degree of compaction and proportioning of ingredients.
4. Fracture characteristics of concrete is mainly depends on pores developed in the concrete structure.
5. Surface structure of concrete is mainly depends on number of pores available in concrete structure.

REFERENCES

[1] Shen, Jiarong, and Qianjun Xu. "Effect of elevated temperatures on compressive strength of concrete." *Construction and Building Materials* 229 (2019): 116846

[2] Peng, Yijiang, et al. "Analysis of the Effect of Porosity in Concrete under Compression Based on DIP Technology." *Journal of Materials in Civil Engineering* 34.1 (2022): 04021376.

[3] Chandrappa, Anush K., and Krishna Prapoorna Biligiri. "Pore structure characterization of pervious concrete using X-ray microcomputed tomography." *Journal of Materials in Civil Engineering* 30.6 (2018): 04018108.

[4] Liu, Ruyan, et al. "Influence of pore structure characteristics on the mechanical and durability behavior of pervious concrete material based on image analysis." *International Journal of Concrete Structures and Materials* 14.1 (2020): 1-16.

[5] Le, Ba-Anh, et al. "Predicting the Compressive Strength and the Effective Porosity of Pervious Concrete Using Machine Learning Methods." *KSCE Journal of Civil Engineering* 26.11 (2022): 4664-4679.

[6] Du Plessis, Anton, et al. "Simple and fast porosity analysis of concrete using X-ray computed tomography." *Materials and structures* 49.1 (2016): 553-562.

[7] Zheng, Xinchao, et al. "Study on durability and pore characteristics of concrete under salt freezing environment." *Materials* 14.23 (2021): 7228

[8] Lopez, W., and J. A. Gonzalez. "Influence of the degree of pore saturation on the resistivity of concrete and the corrosion rate of steel reinforcement." *Cement and concrete research* 23.2 (1993): 368-376.

[9] Lian, Chunqi, Y. Zhuge, and S. Beecham. "The relationship between porosity and strength for porous concrete." *Construction and Building Materials* 25.11 (2011): 4294-4298.

[10] Agar-Ozbek, Ayda S., et al. "Investigating porous concrete with improved strength: Testing at different scales." *Construction and Building Materials* 41 (2013): 480-490.

[11] Zhang, Yi, et al. "Effect of Different Admixtures on Pore Characteristics, Permeability, Strength, and AntStripping Property of Porous Concrete." *Buildings* 12.7 (2022): 1020.

[12] Karanth, Savithri S., U. Lohith Kumar, and Naveen Danigond. "Porous concrete with optimum fine aggregate and fibre for improved strength." *Advances in concrete construction* 8.4 (2019): 305-309.

[13] EL MARZAK, Mounir, et al. "Analysis of the thermal behavior of rubber concrete at elevated temperatures based on the humidity levels: Numerical and mathematical modeling." *Advances in Engineering Software* 172 (2022): 103182.

[14] Saouma, Victor E., et al. "A mathematical model for the kinetics of the alkali–silica chemical reaction." *Cement and Concrete Research* 68 (2015): 184-195.

[15]

[16] Kashef-Haghighi, Sormeh, Yixin Shao, and Subhasis Ghoshal. "Mathematical modeling of CO2 uptake by concrete during accelerated carbonation curing." *Cement and concrete research* 67 (2015): 1-10.

[17] Zhang, Qian. "Mathematical modeling and numerical study of carbonation in porous concrete materials." *Applied Mathematics and Computation* 281 (2016): 16-27.

