



A REVIEW ON POROSITY OF CONCRETE

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Abstract: Porosity in any type of concrete makes a prominent role in strength, Permeability and Fracture properties. In this review study we can presents the investigation on effect of elevated temperature on fresh and hardened properties of concrete. High temperature is well known for seriously damaging micro and meso- scopic structure in concrete. The mechanical properties that are primary interest in fire resistance design are compressive strength, tensile strength, elastic modulus and stress strain response in compression these are the important parameters to be consider for designing fire resistance design of structures. Effect of elevated temperature is influence to both normal strength concrete (NSC) as well as high strength concrete (HSC). In this comprehensive review paper we can gives an overview of behavior of the structure in high elevated temperature. We mainly focused to compressive strength, thermo mechanical effect (stress distribution and cracking), local behavior (spalling and surface micro cracking) and micro structural behavior of concrete etc.

Keywords: Porosity, Spalling, Normal strength concrete (NSC) and High strength concrete (HSC)

1. Introduction

Effect of elevated temperature in a concrete mainly effect to dehydration of cement, due to dehydration of cement number of porosity developed in a concrete.

Hence Porosity in concrete is the important parameter to evaluate the structural parameters in different types of concrete like geo-polymer concrete, porous concrete, fiber concrete, NSC, HSC and structural concrete. Pore structural characteristics of concrete give information about engineering properties like voids, permeability, and rate of flow, length and size of the pores. [1]

Above mentioned properties are important to know the drainage properties as well as compressive strength, micro and mesoscopic characteristics 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 micro cracking characteristics in concrete.

Pore characteristics in structural concrete are mainly effect on tension properties of steel and compressive strength in structural concrete. When the concrete subjected to high temperature it leads to changes of 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]

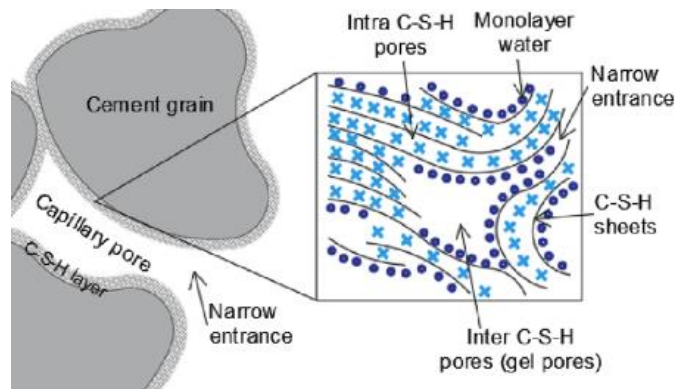


Fig:01 Pore structure diagram

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 hardened concrete has influence on the properties in many aspects.

In the case of fresh concrete pores gaps are 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 varieties 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 of running 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 of pores in a varieties 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.

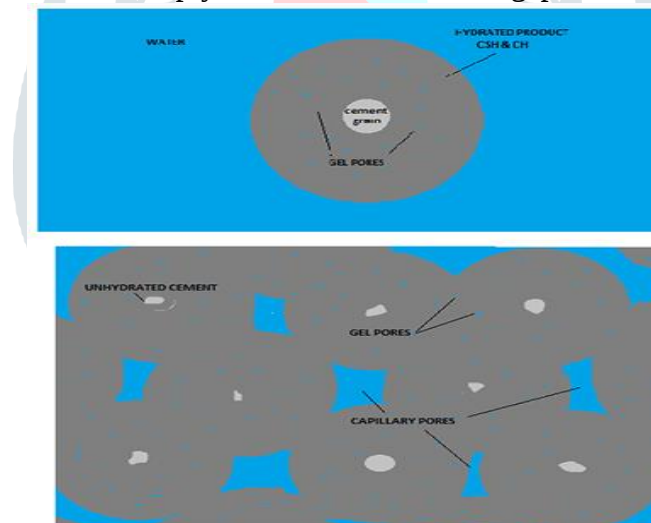


Fig: 02 Development of gel pores and capillary pores in cement paste

Pores in a concrete generally classified into two categories

Based on the size of the pores.

1. Gel pores (<10nm)
2. Capillary pores (10nm -100000nm) [12]

Generally smaller water filled pores are categorised 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

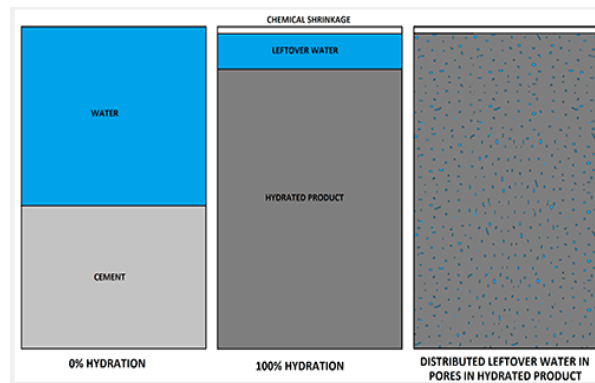


Fig:03 Hydration with water filled pores diagram

In recent years, high-strength concrete (HSC) and mortar (HSM), providing better mechanical and durability properties than normal-strength concrete (NSC) and mortar (NSM), have been widely applied in civil and infrastructure engineering [18]

2. Survey of the factors affecting porosity and mechanical properties of concrete

Main factors that affect to porosity of a concrete was mainly due to elevated temperature and mechanical properties of concrete is vary with different change in temperature. Concrete cubes were prepare according to IS codal provision firstly do mix design according to IS 10262-2009 after mixing of concrete ingredients do casting of concrete moulds specimens then moulds were cured and oven dried at 105°C. Finally concrete cubes subjected to temperature from 100°C to 1000°C [3] then specimen were air cooled and tested. All the experiments were carried out using electric heating furnace of KWh. [1]

Compressive strength

Compressive strength of concrete is reduced when the temperature is raised to 310°C [2], when the concrete Expose to elevated temperature strength properties of concrete get diminished. As we know concrete is strong in compression, due to effect of temperature by means of fire effect to concrete, the bond between the cement pastes get loosened. When the cement paste particle get dispersed the bond between aggregate and cement particle is reduced. Due to this effect strength of the concrete is reduced when the concrete exposed to elevated temperature.

The strength of the porosity concrete with elevated temperature can be evaluated according to equation developed by Ryshkewitch [3]

$$\sigma_p = \sigma_0 e^{-kp}$$

Where,

σ_p = strength of porosity at P%

σ_0 = strength of concrete at zero porosity

K= constant

Tensile strength of concrete

Tensile strength of concrete is less compared to its compression strength without any effect of temperature. When the concrete exposed to fire or temperature bond strength is decreased due to this effect strength of the concrete is reduced. Tensile strength of the concrete is decreases with increasing temperature to 310°C [2]

Micro cracks and spalling of concrete

Elevated temperature is mainly cause to thermo mechanical properties of concrete and micro structural cracks in concrete, this micro structural concrete causes the spalling of concrete. [2]

high strength concrete exhibit lower porosity at room temperature due to dense micro-structure, at high elevated temperature the pore water evaporation from specimen leads to formation of multiple micro cracks and leads to spalling of concrete. [3]

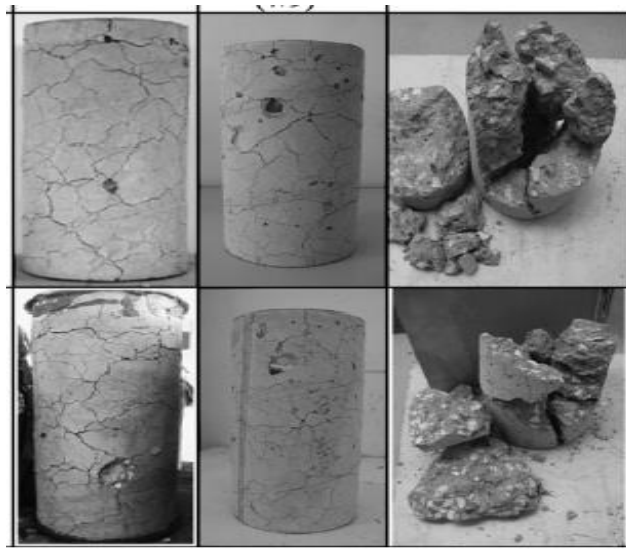


Fig: 2 Micro structures and spalling of concrete [6]

From fig-2 Micro structure of aggregate cause important factor for compressive strength of concrete, surface structure of aggregate influenced to strength properties of concrete. [6] Cracking of aggregate is start from 300°C and spalling of concrete starts from 600°C. [6]

Cracking of aggregate and width of the crack is estimated by using image analysis technique.

		Black Flint	Brown Flint	Grey Flint	Beige Flint
Heating Cycle 300°C	Before heating cycle				
	After heating cycle				
Heating Cycle 450°C	Before heating cycle				
	After heating cycle				
Heating Cycle 600°C	Before heating cycle				
	After heating cycle				

Fig:3 Comparison of different types of flint before and after heating at 300 °C, 450 °C and 600 °C [6]

Control of Explosive spalling of concrete is recommended by euro code 2 in addition to poly propylene fibre [8]. Mesocracks in concrete occurs when the temperature elevated to 400°C.[10]

Modulus of elasticity

Modulus of elasticity of concrete is decreases with increasing temperature [2]. Modulus of elasticity of concrete is mainly depends on pores strength developed in a concrete [3].

Griffith found that the critical stress at crack propagation within a brittle material and can be expressed by $\sigma = \sqrt{\frac{2E\sqrt{a}}{\pi}}$

Where,

σ is the stress at the fracture (N/mm²)

E= young's modulus of elasticity (N/mm²)

$\sqrt{a}$ = Fracture surface energy (J/m²)

a = Half length of the internal crack (m) [17]

Normal strength concrete and high strength concrete

Change in pore volume of concrete both normal strength concrete and high strength concrete is similar up to 600°C beyond this temperature HSC porosity get increased. High strength concrete leads to

Pore pressure at elevated temperature

Pore pressure built up in a concrete material under elevated temperature is most important for knowing explosive spalling of concrete. Concrete exposed to elevated temperature pore water pressure get passed out from the concrete pores its leads to cracks in concrete surface. [4]

Total pores available in a concrete sample to be evaluated by using the equation

$$P = 1 - (\rho_b / \rho_t)$$

Where,

P = Total porosity

ρ_b = Bulk density of sample

ρ_t = Total density of sample [17]

Permeability

High elevated temperature leads to lower porosity due to dense property with fewer voids in a concrete at room temperature. At elevated temperature pores in a concrete get distracted make a concrete to higher permeability. [4] [22]

Mesoscopic and residual compressive strength of high strength concrete and mortar containing blast furnace slag (BFS) leads to less porosity. In this review study authors find the development of temperature in a concrete within furnace can be noticed and temperature developed in a furnace can be divided into 4 phases

1. Constant temperature phase
2. Increasing temperature phase
3. Fast cooling phase
4. Slow cooling phase

$$q_c = h(T_1 - T_2)$$

Where,

q_c = Heat flux in convection (W/m^2)

cracks in high strength concrete and high strength mortar increased with increasing the temperature, micro morphology of the paste loose more and more from $400^{\circ}C$ - $800^{\circ}C$. [10]

Loss of weight

After concrete subjected to elevated temperature weight of the concrete get reduced, this weight loss leads to decrease in strength and increase in porosity of the concrete. Temperature elevated to $100^{\circ}C$ concrete losses the weight about 1.8-28%. [7]

3. Common Tests Applied To Investigate the Porosity of Concrete

- Elevated temperature test programme
- Permeability test
- Compressive test
- Air content test for fresh concrete
- Tensile strength of concrete
- Scanning electronic microscopy (Image Analysis) Gravimetric method

Elevated temperature test programme

After curing of concrete at 28 days concrete mould to be dried out with different elevated temperature. After elevated to different elevated temperature cubes to be involved for different experimental work. Electric furnaces with concrete cubes as shown in the fig-04.



Fig: 04 Electric furnaces

Permeability test:

Permeability characteristics of concrete to be evaluated 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.[11]

Compressive strength

Compressive strength of the concrete cubes to be evaluated based on conduction of the experiment as 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.[8][9][7] compressive strength of the concrete to be predict by using machine learning method. [15] Compressive strength of the concrete is increased by adding different admixture in concrete [18].

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. [14]

Tensile strength of concrete

The split tensile strength of concrete is to be conducted as per Indian standard 5816. The tensile strength properties of concrete are lower when the temperature increases above 400° C.

Scanning electronic microscopy (Image Analysis)

The SEM is an instrument that produces a largely magnified image by using electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum.[5]

Gravimetric method

The gravimetric technique proposed by Montes et al. [20] Has been used by researchers such as Candaele et al. [21] and Manahiloh et al. [22] to determine the Porosity of concrete. The test was performed on Concrete cube specimens of 100 mm dimension.

4. Codes and Standards

- Indian Standard Codes
- Euro Codes
- ACI codes

Indian standard codes

Fire resistance provisions in Indian standard code are prescriptive in nature and provide fire rating in structural members. The provision for fire resistance given in IS 456:2000 and IS 1642:1988 gives the tabulated values for fire ratings for beams and columns. Recommendation of hot weathering concreting was evolved on 22nd September 1975, IS-7861 part-I encountered in the preparation, placement and curing of concrete in hot weathering. High temperature leads to high heat of hydration and increasing the evaporation of mixing water, the object of this code is to identify the problems of hot weather concreting practice. [11]

Euro codes

A Euro code gives simplified method of equations for fire resistant design. This code gives information about effect of temperature on civil works.

EN 1991-1-5 gives design guidance for thermal actions arising from climatic and operational conditions on buildings and civil engineering works. Information on thermal actions induced by fire is given in EN 1991-1-2. EN 1991-1-5 is intended for clients, designers, contractors and relevant authorities. EN 1991-1-5 is intended to be used with EN 1990, the other Parts of EN 1991 and EN 1992-1999 for the design of structures. [12]

ACI code

ACI 305.1-14, sections 3.2 and 3.3, recommends a maximum temperature of fresh concrete at time of discharge to not exceed (35°C), unless supporting field experience or pre-construction testing is available. This guide identifies problems associated with hot weather concreting and describes practices that alleviate these potential adverse effects. These practices include suggested preparations and procedures for use in general types of hot weather construction, such as pavements, bridges, and buildings either cast in place or

precast. Temperature, volume changes, and cracking problems associated with mass concrete are treated more thoroughly in ACI 207.1R, 207.2R, and 224R. [13]

5. Discussion on the major factor that contributes to the porosity of concrete

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

Inadequate water mix proportions

Different morphological properties of coarse aggregates

- Air content
- Cement paste volume
- Improper compaction
- Degree of hydration [1]
- Calcium silicate hydrate gel
- Inadequate water mix proportions
- Morphological properties of coarse aggregate

Air content

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

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.

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.

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

Calcium silicate hydrate gel

Calcium silicate hydrate influenced to mechanical properties of concrete that reduces the strength and increase the porosity in concrete.

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 recommendations from Indian standard. From trial and error method we fix the w/c ratio and from previous researchers carried out.

Different morphological properties of coarse aggregates

Based on aggregate shape it can be classified into following categories

- Rounded
- Irregular
- Flaky aggregate
- Elongated aggregate

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

CONCLUSIONS

Porosity of concrete mainly depends on morphological characteristics of coarse aggregate, volume of the cement paste, air content and degree of hydration. Size and number of pores is mainly depends on degree of compaction and proportioning of ingredients. Meso-microscopic characteristics of concrete occur at a temperature above 400°C. When the temperature increased above 400°C both micro cracks as well as spalling of the concrete occurs.

Elevated temperature influenced to all varieties of concrete like normal strength concrete, high strength concrete, porous concrete, fiber reinforced concrete. [4][6][7][9] Mathematical modeling to be developed for relating the strength and permeability of the concrete based on Griffith theory. [17]

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