Module # 5

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1. Thermal Properties of Concrete

Thermal Properties of concrete

Introduction

- Thermal properties of a concrete can be defined as the effect of the heat and high temperature on the concrete.
- Concrete is a material used in all climatic regions for all kinds of structures.
- Thermal properties are important in structures in which temperature differentials occur including those due to solar radiation during casting and the inherent heat of hydration.
- The thermal properties of concrete are more complex than those of most other materials because these are affected by moisture content, cement content, heat of hydration, type of aggregate, size of aggregate and much more.

Thermal Properties of concrete

To study about the thermal properties of concrete the following properties needs to be known:

1. Thermal conductivity.
2. Thermal diffusivity.
3. Specific heat.
4. Coefficient of thermal expansion.

Thermal Properties of concrete

1. Thermal conductivity

- The thermal conductivity of concrete is one of the key parameters needed to predict temperature variation during hydration.
- This measures the ability of the material to conduct heat.
- Defined as the ratio of the flux of heat to temperature gradient.
- The major factors influencing the conductivity are the moisture content of concrete, the type of aggregate, the mix proportions, the type of cement and the temperature of the concrete.
- **$k = Q * L / A(T2 - T1)$**
- Where:
  Q = heat flow (W)
  L = length or thickness of the material (m)
  A = surface area of material (m2)
  T2−T1 = temperature gradient

Thermal Properties of concrete

2. Specific Heat

- Specific Heat is defined as the quantity of heat required to raise the temperature of a unit mass of concrete by 1 ^{o}C.
- The Common range of values for concrete is between 840 and 1170 J/kg per 1 ^{o}C.
- Specific heat represents the heat capacity of concrete.
- It increases with the moisture content of concrete and is affected by the mineralogical character of the aggregate,
- Specific heat increases with an increase in temperature.
- It also increases with a decrease in the density of concrete

Thermal Properties of concrete

3. Thermal diffusivity

- Thermal diffusivity is a measure of the rate at which temperature change within the mass take place.
- The larger the value of thermal diffusivity of a mass the faster the changes will occur.
- The value of thermal diffusivity is dependent on the aggregate type, moisture content, degree of hydration of the cement paste, and exposure to drying.
- Diffusivity can be determined by:
- **D = K/Sd**

D = Thermal diffusivity (m2/s)

K = Thermal conductivity (J/s)

S = Specific heat (J/kg)

d = Density of concrete (kg/m3)

Thermal Properties of concrete

4. Coefficient of the thermal expansion

- Coefficient of the thermal expansion is defined as the change in unit length per degree change in the temperature.

It depends upon:

- Composition of mix
- Coefficient of expansion of cement concrete paste.
- Coefficient of expansion of aggregate.

Thermal Properties of concrete

4. Coefficient of the thermal expansion

- The coefficient of thermal expansion is usually expressed in micro-strains per unit temperature change.
- The coefficient of thermal expansion of Portland cement concrete (PCC) ranges from about 8 to 12 micro-strains/°C.
- The range of coefficient of thermal expansion values for different concretes reflects the variation in coefficient of thermal expansion of concrete's component materials.
- For example, concrete containing limestone aggregate has a lower coefficient of thermal expansion than concrete containing siliceous aggregate. Because aggregate comprises about 70% of the concrete, aggregate type has the greatest effect on the coefficient of thermal expansion of concrete.

Thermal Properties of concrete

Typical α ranges for common PCC components.

	Coefficient of Thermal Expansion	
	10^{-6}/°C	10^{-6}/°F
Aggregate		
Granite	7-9	4-5
Basalt	6-8	3.3-4.4
Limestone	6	3.3
Dolomite	7-10	4-5.5
Sandstone	11-12	6.1-6.7
Quartzite	11-13	6.1-7.2
Marble	4-7	2.2-4
Cement Paste (saturated)		
w/c = 0.4	18-20	10-11
w/c = 0.5	18-20	10-11
w/c = 0.6	18-20	10-11
Concrete	7.4-13	4.1-7.3
Steel	11-12	6.1-6.7

Thermal Properties of concrete

Thermal Coefficient Of Portland Cement Concrete

- The coefficient of thermal expansion is calculated according to the following formula:
- coefficient of thermal expansion = $(\Delta L/L_0) / \Delta T$

where

- ΔL = length change of specimen,
- L_0 = initial measured length of specimen, and
- ΔT = temperature change.

2. Extensibility and Cracking

Extensibility and Cracking

Extensibility and Cracking

- As stated earlier, the primary significance of deformations caused by applied stress and by thermal and moisture-related effects in concrete would lead to cracking.
- Thus the magnitude of the shrinkage strain is only one of the factors governing the cracking of concrete.

It is clear that the other factors are:

- **Modulus of elasticity**
- **Creep**
- **Tensile strength**

The combination of factors that are desirable to reduce the advent of cracking in concrete can be described by a single term called **extensibility**.

3. Water as an agent of deterioration

Water as an agent of deterioration

- Concrete is the material defenseless to physical and chemical processes of deterioration associated with water.
- Therefore it is desirable to review, in general, the characteristics of water that make it the principal agent of destruction of solid materials.
- Water in its various forms, such as seawater, groundwater, river water, lake water, snow, ice, and vapor, is undoubtedly the most abundant fluid in nature.
- Water molecules are very small and, therefore, are able to penetrate into extremely fine pores or cavities.
- As a solvent, water is noted for its ability to dissolve more substances than any other known liquid.
- This property accounts for the presence of many ions and gases in some waters which, in turn, become instrumental in causing deterioration of concrete in sense of chemical attack.

Water as an agent of deterioration

- Also, water has the highest heat of vaporization among the common liquids; therefore, at ordinary temperatures it has a tendency to exist in the liquid state in a porous material, rather than vaporizing and leaving the material dry.
- Furthermore, with porous solids, internal moisture movements and structural transformations of water are known to cause disruptive volume changes of many types.
- For example, freezing of water into ice, formation of an ordered structure of water inside the fine pores, development of osmotic pressure due to different ionic concentration can lead to high internal stresses.

4. Permeability of Concrete

Permeability of Concrete

- **Permeability** is defined as the property that governs the rate of flow of a fluid into a porous solid.
- Permeability of concrete is the property of concrete to absorb water
- If the concrete is impermeable than corrosive agents cannot penetrate and attack it.
- Concrete has small pores whose diameter varies from 0.01 to 10 micron in cement pastes
- Factors affecting permeability of concrete:-
  1. Water-Cement Ratio
  2. Improper Compaction of Concrete
  3. Improper Curing
  4. Age of concrete
  5. Pore structure
  6. Degree of compaction

5. Classification of causes of concrete deterioration

Classification of causes of concrete deterioration

1. Frost Action

- Freeze/thaw damage occurs in concrete when the water molecules in concrete freeze and expand beyond the volume constraints of the concrete.
- When the 91% of the pores of concrete are filled with water, the concrete is known to be saturated.
- When these water molecules freeze, they expand by 9%, and because there is no room for their increased volume, the concrete distresses.
- The freeze can cause to weak the bonds in cement around the aggregate to break and the concrete can crack in those places.
- As the water in moist concrete freezes, it produces pressure in the capillaries and pores of the concrete.
- If the pressure exceeds the tensile strength of the concrete, the cavity will rupture.

Pavement damage due to Freeze Thaw Cycles

Classification of causes of concrete deterioration

1. Frost Action

- Frost Action is a major cause of deterioration of concrete in Cold Climates. It takes place due to freezing or water within the concrete pores and cavities during extremely cold weather.
- Water on freezing expands and exerts pressure on the walls of the pores. This cyclic freezing of water in the pores are responsible for the development of cracks of various nature in the concrete.

To minimize frost actions following measures should be taken:

1. In cold weather, the water-cement ratio should be kept as low as possible. This will not allow any extra water to remain within the concrete pores. Hence frost formation will not take place.
2. Use good drainage and covering methods for removing any surface water from staying on the concrete during the curing process.

Classification of causes of concrete deterioration

1. Frost Action

Aggregate Expansion

- Some aggregates may absorb so much water (to critical saturation) that they cannot accommodate the expansion and hydraulic pressure that occurs during the freezing of water.
- The result is expansion of the aggregate and possible disintegration of the concrete. If a problem particle is near the surface of the concrete, it can cause a popout.

Classification of causes of concrete deterioration

2. Effect of fire

- The concrete as a building material has a very good behavior when it exposed to fire, especially when it is compared to any others building materials like wood and steel.
- But this is not mean that the concrete has infinite fire resistance, in some levels of fires when the concrete exposed to high temperature up to 900 º C, significant changes in the mechanical properties of the structural elements like stiffness and strength will be occur.

Physical and chemical response to fire

100 to 140°C - Evaporation of the free water inside the concrete mix.

300°C - The cement paste will start to shrink due to water evaporation and the aggregate will expand. This will cause damage which is called the spalling of concrete.

400 to 600°C - the calcium hydroxide in the cement paste breaks to calcium oxide and water. The resultant water from the chemical reaction, start to evaporate. This will cause a significant reduction in the concrete strength.

Classification of causes of concrete deterioration

2. Effect of fire

Spalling of concrete

The spalling of concrete is the breaking and splitting of the concrete elements surface layers due to high thermal exposure. The spalling can be classified to three types.

A. Aggregate spalling.
B. Corner & surface spalling.
C. Explosive spalling.

If the spalling happened to the concrete column, the column may collapse may collapse due to buckling.

Classification of causes of concrete deterioration

2. Effect of fire

Factors influencing the explosive spalling

1. Heating Rate, the probability of explosive spalling to occur increasing with the increasing of the heating rate.

2. The exposure of the element to the fire, the more faces of structural elements are exposed to fire, the probability of the spalling to occur increased.

For example, slabs have better resistance than the beams this because there is only one face of the slabs are exposed to fire unlike beams 3 faces exposed to fire.

3. Age of concrete structure, most of the research papers indicate that the probability of the concrete spalling decrease with the increasing of the structure age. This is because when the concrete structure age increase, the moisture content is decreasing. As a result of that significant decrease will happened in the generated pore pressure and the internal tension stresses

4. Aggregates type, the probability of spalling decrease when low thermal expansion aggregates are used.

5. Aggregate size, most of research papers and the results from the experiments indicates that the greater size of the aggregate, more likely explosive concrete spalling is to occur.

6. Cover to reinforcement, It is founded that if the concrete cover with thickness less than 15mm has high probability for the spalling of the concrete cover.

Classification of causes of concrete deterioration

3. Sulphate attack

- Sulphate attack on concrete is a chemical breakdown mechanism where sulphate ions attack components of the cement paste.
- The compounds responsible for sulphate attack on concrete are water-soluble sulphate-containing salts, such as alkali-earth (calcium, magnesium) and alkali (sodium, potassium) sulphates that are capable of chemically reacting with components of concrete.

Forms of Sulphate Attack on Concrete

Sulphate attack on concrete might show itself in different forms depending on:

- The chemical form of the sulphate
- The atmospheric environment which the concrete is exposed to.

What happens when sulphates get into concrete?

When sulphates enters into concrete:

- It combines with the concrete paste, and begins destroying the paste that holds the concrete together. As sulphate dries, new compounds are formed, often called **ettringite**.
- These new crystals occupy space, and as they continue to form, they cause the paste to crack, further damaging the concrete.

Classification of causes of concrete deterioration

4. Alkali-Aggregate Reaction.

- Sodium and potassium hydroxides of cement are capable of reaction with silica.
- Since amorphous silica is a common component of many coarse aggregates, such an alkali-aggregate reaction may create harmful effects on cement concrete.
- This is because the gel-like silicate structures produced by the above reaction are quite weak and unstable and result in greater expansion.
- These may be the cause of frequent cracking in some concrete.
- For avoiding this reaction, either the percentage of alkalies (K_2O and Na_20) has to be kept very low in the Portland Cement.
- Or a great care has to be taken for selecting aggregates free of silica.

Assignment #1 (Submission After Mid Exam)

Concrete in Marine Environment

- Composition of sea water
- Effect of sea water of concrete structure
- How to improve durability of concrete structure which are exposed to marine conditions


The End