Concrete
Types and Properties

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Introduction:

Concrete is a composite material that consists essentially of a binding medium, such as a mixture of portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate. Concrete is by far the most versatile and most widely used construction material worldwide. It can be engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used as they are. Because the tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars, in which case it is known as reinforced concrete.

Materials: A composite material is made up of various constituents. The properties and characteristics of the composite are functions of the constituent materials' properties as well as the various mix proportions. Before discussing the properties of the composite, it is necessary to discuss those of the individual constituents as well as the effects of the mix proportions and methods of production.

Cement: There are many different kinds of cements. In concrete, the most commonly used is Portland cement, hydraulic cement which sets and hardens by chemical reaction with water and is capable of doing so under water. Cement is the "glue" that binds the concrete ingredients together and is instrumental for the strength of the composite. Although cements and concrete have been around for thousands of years, modern portland cement was invented in 1824 by Joseph Aspdin of Leeds, England. The name derives from its resemblance of the natural building stone quarried in Portland, England.

Aggregate:

The aggregate is a granular material, such as sand, gravel, crushed stone or iron-blast furnace slag. It is graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [4.75 mm openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone. By carefully grading the material and selecting an optimal particle size distribution, a maximum packing density can be achieved, where the smaller particles fill the void spaces between the larger particles. Such dense packing minimizes the amount of cement paste needed and generally leads to improved mechanical and durability properties of the concrete.

Admixtures:

While aggregate, cement, and water are the main ingredients of concrete, there are a large number of mineral and chemical admixtures that may be added to the concrete. The four most common admixtures will be discussed below:

1. Air-entraining agents: are chemicals that are added to concrete to improve its freeze–thaw resistance. Concrete typically contains a large number of pores of different sizes, which may be partially filled with water. If the concrete is subjected to freezing temperatures, this water expands when forming ice crystals and can easily fracture the cement matrix, causing damage that increases with each freeze–thaw cycle. If the air voids created by the air-entraining agent are of the right size and average spacing, they give the freezing water enough space to expand, thereby avoiding the damaging internal stresses.

2. Water-reducing admixtures (super plasticizers): are chemicals that lower the viscosity of concrete in its liquid state, typically by creating electrostatic surface charges on the cement and very fine aggregate particles. This causes the particles to repel each other, thereby increasing the mix flow ability, which allows the use of less water in the mix design and results in increased strength and durability of the concrete.

3. Retarding admixtures: delay the setting time, which may be necessary in situations where delays in the placement of concrete can be expected. Accelerators shorten the period needed to initiate cement hydration—for example, in emergency repair situations that call for the very rapid development of strength or rigidity.

4. Color: pigments in powder or liquid form may be added to the concrete mix to produce colored concrete. These are usually used with white Portland cement to attain their full coloring potential.

Reinforcing steels:

Because of concrete's relatively low tensile strength, it is typically reinforced with steel bars. These bars are produced in standard sizes. In the United States, the identification number of a reinforcing bar refers to the nominal diameter expressed in eighths of an inch. For example, a number 6 bar has a diameter of 6/8=0.75 inch. The available bar sizes range in general from 2 to 18. Reinforcing steel usually has nominal yield strength of (414 MPa). To improve the bond strength between the bars and the concrete, the bars are fabricated with surface deformations or ribs.

Standard Specifications:

American Society for Testing and Materials (ASTM) and the American Concrete Institute (ACI), and the American Association of State Highway and Transportation Officials (AASHTO), have published detailed specifications and recommendations for measuring, mixing, transporting, placing, curing, and testing concrete. A proper mix design assures that the concrete mix is well proportioned. The mixing time should be sufficient to assure a uniform mixture. When placing the concrete, care should be taken to avoid segregation. For example, if dropped too far, the heavy or big aggregate particles can settle and lighter mix components, such as water, tend to rise. The concrete is conveyed from the mixing truck to its final destination in dump buckets by cableways or cranes or by pumping through pipelines. In modern high-rise building construction, concrete has been pumped as high as a thousand feet (330 m).

Curing:

Once the concrete has been placed and compacted, it is critical that none of the mixing water needed for cement hydration is lost. This is the objective of curing. For example, in hot or dry weather large exposed surfaces will lose water by evaporation. This can be avoided by covering such surfaces with sheets of plastic or canvas or by periodically spraying them with water. In precast concrete plants, concrete elements are often steam-cured, because the simultaneous application of hot steam and pressure accelerates the hydration process, which permits high turnover rates for the formwork installations.

Properties of fresh concrete:

The most important property of fresh concrete is its workability or flowability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete (Fig. 2). The mold is then lifted vertically, and the resulting loss in height of the concrete cone, or the slump value, is indicative of the concrete's workability. For very liquid mixes, the flow test is performed, which is similar to the slump test, except that the mean diameter of the cake formed by the fresh concrete (or mortar) is measured.

A short while after casting, the concrete stiffens and loses its plasticity. The time of setting can be determined by repeatedly dropping a calibrated needle into the fresh concrete and measuring the time when the needle no longer sinks in.

Figure 1: Slump test.

Properties of hardened concrete:

By far, the most important property of hardened concrete is its compressive strength. Since this strength continues to increase with continuing cement hydration, it is a function of age which is the time after casting. In the United States, the strength is determined 28 days after casting by loading standardized test cylinders up to failure. In Europe, test cubes are often used. Most commercially produced concrete has compressive strengths between (20 and 40 MPa). If loaded in tension, the material fails at a stress much lower than that, typically of the order of 10% of the compressive strength. Because of this low (and unreliable) tensile strength, concrete is usually reinforced with steel bars.

Durability:

Durability is the ability of a material (or structure) to maintain its various properties throughout its design or service life. Some concrete structures built by the Romans served for over 2000 years. A material that loses its strength in time, for whatever reason, cannot be considered durable. There can be numerous causes for loss of durability or deterioration of concrete structures. The most common one is an excessive amount of cracking or pore structure. Most concrete structures contain numerous cracks. But as long as these remain small (0.25 mm or less), they are generally invisible to the naked eye, and the concrete remains basically impermeable to salts and other aggressive agents, so that it can continue to protect the reinforcing steel against corrosion. Larger cracks provide easy access for such agents to the steel, thereby promoting corrosion. Since the steel corrosion products occupy a larger volume than sound steel, they produce internal pressure during expansion and can spall off the protective concrete cover, the loss of which may render the structure unsafe to resist loads.

Thermal and other properties:

The heavy weight of concrete [its specific gravity is typically 2.4 g/cm^3] is the source of large thermal mass. For this reason, massive concrete walls and roof and floor slabs are well suited for storing thermal energy. Because of this heat capacity of concrete, together with its reasonably low thermal conductivity, concrete structures can moderate extreme temperature cycles and increase the comfort of occupants. Well-designed concrete mixes are impermeable to liquids and therefore suitable for storage tanks without the need for impermeable membranes or liners. Although steel reinforcing bars conduct electricity and influence magnetic fields, the concrete itself does neither.

Special concrete types and recent developments:

Concrete is an engineered material, with a variety of specialty products designed for specific applications. Some important ones are described below:

1. Lightweight concrete: Although the heavy weight or large mass of typical concrete members is often an advantage, there are situations where this is not the case. For example, because of the large stresses caused by their own heavy weight, floor slabs are often made lighter by using special lightweight aggregate. To further reduce weight, special chemical admixtures are added, which produce large porosity. Such high porosity (in either the matrix or the aggregate particles themselves) improves the thermal resistance of the concrete as well as sound insulation, especially for higher frequencies. However, because weight density correlates strongly with strength, ultra lightweight concretes [1.1 g/cm^3) and less] are used only for thermal or sound insulation purposes and are unsuitable for structural applications.

2. Heavyweight concrete: When particularly high weight densities are needed, such as for shielding in nuclear reactor facilities, special heavyweight aggregate is used, including barite, limonite, magnetite, scrap metal, and steel shot for fine aggregate. Weight densities can be achieved that are twice that of normal weight concrete.

3. Architectural concrete:

Concrete surfaces that remain exposed may call for special finishes or textures according to the architect's desires. Textures are most readily obtained by inserting special form liners before casting the concrete. Sometimes the negative imprint of roughly sawn timber is considered attractive and left without further treatment.

4. Fiber-reinforced concrete:

The concrete matrix can be reinforced with short, randomly distributed fibers. Fibers may be metallic, synthetic (such as polypropylene, nylon, polyethylene). Such fibers are typically used in addition to conventional steel reinforcement, but in some applications as its replacement. For example, precast glass-fiber reinforced building façade elements are widely used in the United States. By being uniformly distributed and randomly oriented, the fibers give the concrete matrix tensile strength, ductility, and energy absorption capacities that it otherwise would not have.

5. Textile-reinforced concrete:

Whereas in fiber-reinforced concrete the fibers are short [usually no longer than 5 cm] and discontinuous, textile-reinforced concrete contains continuous woven or knitted mesh or textiles. Conceptually, such reinforcement acts similarly to conventional steel reinforcing bars or welded steel wire fabrics. But these fabric materials are noncorrosive and can have mechanical properties that are superior to those of steel.

6. Polymer-modified concrete:

In polymer-modified concrete, also known as latex-modified concrete, a polymer is added to improve the material's strength, imperviousness, or both. In applications such as highway bridge decks, often a layer of latex-modified concrete is placed on top of a regular reinforced concrete deck for additional protection of the steel reinforcement. In polymer concrete, the hydraulic cement is replaced by an organic polymer as the binder.

7. Roller-compacted concrete:

This type of concrete is formulated with very low contents of portland cement and water and therefore is of relatively low-cost. It is often used for pavements and dams. It can be transported by dump trucks or loaders, spread with bulldozers or graders, and compacted with vibratory rollers. Because the cement content is so low, the heat of hydration does not cause the kind of problems encountered in dams built with conventional concrete.

8. Ultra-high-strength concrete:

Whereas concretes with compressive strengths of (40 to 85 MPa) can now be categorized as high-strength, a new technology has been developed that results in strengths of (200 MPa) and higher. The key ingredient of this ultra-high-strength concrete is a reactive powder; therefore, it is also known as reactive-powder concrete.

9. Self-leveling concrete:

The need for good workability has been mentioned. The need for highly skilled workers who can properly compact concrete at the construction site prompted researchers in Japan to optimize the mix design such that the fresh concrete can flow into place without the need for further vibration. The main challenge was to obtain a low viscosity mix without the threat of desegregation.

10. Green concrete:

Concrete is by far the most widely used building material. Well over 10 billion tons are produced worldwide each year, requiring enormous natural resources. Also, it has been estimated that the production of 1 ton of portland cement causes the release of 1 ton of carbon dioxide (CO_2) into the atmosphere, a gas that is known to contribute to global warming. Together with the large amounts of energy required to produce portland cement, the cement and concrete industry has a major impact on the environment worldwide.

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