

Chapter II: Concrete and Steel



1. Concrete



Concrete was also used extensively in the construction of Gothic cathedrals during the Middle Ages. The Sagrada Familia in Barcelona, which is still under construction, is a particularly notable example of the use of concrete in Gothic architecture.



In the 19th and 20th centuries, concrete became even more popular among architects. Frank Lloyd Wright, Louis Kahn, and Le Corbusier are just a few of the

many famous architects who used concrete in their designs. Wright's Fallingwater house is a classic example of his use of concrete. The house is cantilevered over a waterfall, and the concrete walls and floors blend seamlessly with the natural surroundings.



Frank Gehry's Guggenheim Museum Bilbao is another iconic example of the use of concrete in architecture. The museum's curving titanium-clad exterior is supported by a complex concrete structure.



Louis I. Kahn's Louis I. Kahn Center for British Art at Yale University is a striking example of his use of concrete. The building features a massive concrete façade with deep recesses that create a sense of monumentality.



Today, concrete is used in a wide range of architectural projects, from skyscrapers to bridges to houses. It is a versatile and durable material that offers architects a great deal of creative freedom.

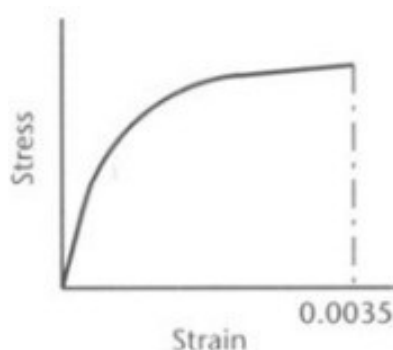
Concrete can also be used to create sustainable and environmentally friendly buildings. LEED Gold and Net Zero Carbon concrete buildings are becoming increasingly common. Concrete can also be made with recycled materials, which can help to reduce the environmental impact of construction projects.



B. 1.2. Behavior of concrete

1.2.1. Behavior of concrete failing in compression

Concrete can fail under certain conditions, especially when subjected to excessive **compressive loads**. Concrete under compression behaves in a linear elastic manner up to a certain point. This means that the stress and strain are proportional to each other. However, after a certain point, the concrete begins to yield and the stress-strain relationship becomes non-linear. The concrete eventually fails in compression when the stress reaches the compressive strength of the concrete. A typical curve for concrete in compression is shown in the following figure.



Here are some of the typical mechanical properties of concrete:

Property	Value
Compressive strength	20 - 40 MPa
Modulus of elasticity	14 - 41 GPa

1.2.2. Factors affecting concrete compressive strength

Among the large number of factors affecting the compressive strength of concrete, the following are probably the most important for concretes used in structures:

1. Water/cement ratio: the strength of concrete is governed in large part by the ratio of the weight of the water to the weight of the cement for a given volume of concrete. A lower water/cement ratio reduces the porosity of the hardened concrete and thus increases the number of interlocking solids.

2. Type of cement: there are many different types of cement available, each with its own unique properties. The most common type of cement is:

- **Portland cement:** is a hydraulic cement, which means that it hardens when it reacts with water. Portland cement is made from a mixture of limestone, clay, and other minerals. It is the most widely used type of cement in the world.



Other types of cement include:

- Pozzolana cement: is a type of cement that contains pozzolans, which are materials that react with calcium hydroxide to form cementitious compounds. Pozzolana cement is more resistant to sulfate attack and has a lower heat of hydration than Portland cement.



- Slag cement: is a type of cement that contains ground granulated blast furnace slag, which is a byproduct of the iron and steel industry. Slag cement is more resistant to sulfate attack and has a lower heat of hydration than Portland cement.



The type of cement that is used in a particular application will depend on the specific requirements of the application. For example, Portland cement is typically used for general concrete construction, while pozzolana cement is often used for concrete that is exposed to sulfate attack.

Here is a table that summarizes the different types of cement and their typical applications:

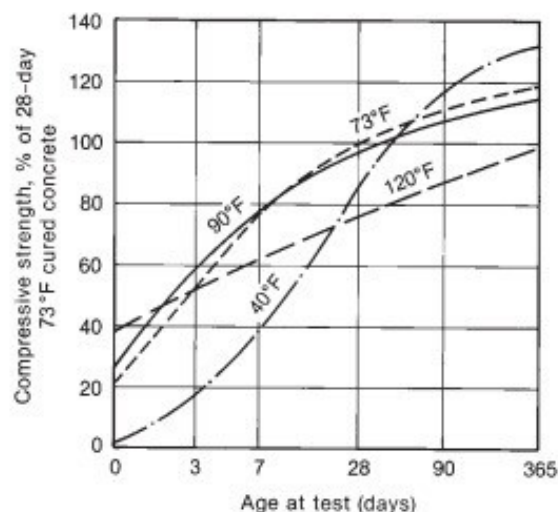
Type of cement	Typical applications
Portland cement	General concrete construction
Pozzolana cement	Concrete exposed to sulfate attack, concrete with low heat of hydration requirements
Slag cement	Concrete exposed to sulfate attack, concrete with low heat of hydration requirements
White cement	Decorative concrete, terrazzo
Expanding cement	Precast concrete, repair mortars, applications where shrinkage must be minimized

3. Supplementary cementitious materials: sometimes, a portion of the cement is replaced by materials such as fly ash, ground granulated blast-furnace slag, or silica fume to achieve economy, reduction of heat of hydration, and, depending on the materials, improved workability.

4. Aggregate: the strength of concrete is affected by the strength of the aggregate, its surface texture, its grading, and, to a lesser extent, by the maximum size of the aggregate.

5. Mixing water: there are no standards governing the quality of water for use in mixing concrete. In most cases, water that is suitable for drinking and that has no pronounced taste or odor may be used.

6. Temperature conditions during curing: the effect of curing temperature on strength gain is shown in the bellow figure.



7. Age of concrete: concrete strength increases with age. This is because the cement paste continues to hydrate and harden over time.

8. Type of load: The type of load that concrete is subjected to can also affect its behavior. Concrete under sustained loads, such as the weight of a building, will behave differently than concrete under dynamic loads, such as the impact of an earthquake.

C. 1.3. International standards

Here is a list of some of the most widely used design codes for concrete structures:

- **Eurocode 2:** Design of concrete structures - Part 1-1: General rules and rules for buildings (EN 1992-1-1): This is the primary design code for concrete structures in Europe. It provides comprehensive guidelines for the design, analysis, and detailing of reinforced concrete and prestressed concrete structures.
- **ACI 318-23:** Building Code Requirements for Structural Concrete: This is the most widely used design code for concrete structures in the United States. It is published by the American Concrete Institute (ACI) and provides comprehensive guidelines for the design, analysis, and detailing of reinforced concrete and prestressed concrete structures.

D. 1.4. Quality control and inspection

Quality control and inspection of concrete are essential processes in ensuring the safety, durability, and performance of concrete structures. These procedures involve various activities to verify that the concrete meets the specified requirements and achieves the desired properties.

1. Concrete

1. Quality Control:

Quality control encompasses all measures taken throughout the concrete production and construction process to ensure the consistent production of high-quality concrete. It involves planning, monitoring, and testing to identify and address potential problems before they cause significant defects or failures.

Key aspects of quality control include:

- **Material Selection and Testing:** Ensuring the quality of cement, aggregates, admixtures, and water used in concrete production.
- **Concrete Mix Design:** Developing and implementing appropriate concrete mix designs that meet the specified strength, workability, and durability requirements.
- **Batching and Mixing:** Accurate batching of concrete ingredients and proper mixing to achieve a homogeneous and consistent concrete mixture.
- **Transportation and Placement:** Ensuring proper transportation and placement of concrete to prevent segregation, loss of workability, or premature hardening.
- **Curing:** Implementing proper curing procedures to maintain adequate moisture and temperature conditions for hydration of cement and strength development.
- **Testing and Monitoring:** Conducting regular testing of fresh and hardened concrete to assess its properties, identify any deviations from specifications, and make necessary adjustments.

2. Inspection

Inspection involves physical examination and evaluation of concrete construction activities, materials, and finished products to ensure compliance with specified requirements and quality standards. It serves as a verification of the effectiveness of quality control measures.

Key aspects of inspection include:

- **Visual Inspection:** Examining the concrete surface for cracks, honeycombs, voids, segregation, and other visible defects.
- **Formwork Inspection:** Verifying that forms are properly constructed, aligned, and supported to prevent leaks or movement during concrete placement.
- **Reinforcement Inspection:** Ensuring that reinforcement is properly placed, spaced, and secured according to the design drawings and specifications.
- **Concrete Testing:** Conducting non-destructive testing (NDT) methods, such as rebound hammer, ultrasonic testing, and core testing, to assess the in-situ strength and integrity of concrete.
- **Documentation:** Maintaining accurate records of inspections, test results, and any non-conformance issues to track the quality of concrete throughout the construction process.

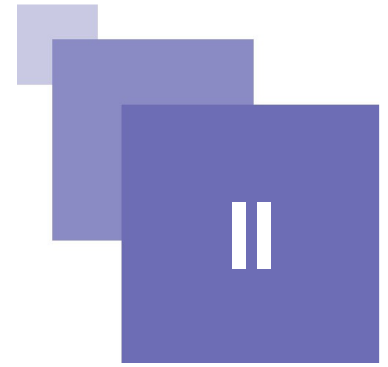
3. Importance of Quality Control and Inspection

Quality control and inspection are crucial for ensuring the safety, durability, and performance of concrete structures. They help to:

- **Prevent Failures:** Identify and address potential problems early on, reducing the risk of structural failures or costly repairs.
- **Ensure Compliance:** Verify that concrete meets the specified requirements and design assumptions, ensuring the structural integrity of the building.
- **Enhance Durability:** Ensure the concrete's resistance to weathering, corrosion, and other environmental factors, extending the lifespan of the structure.
- **Maintain Quality Standards:** Maintain consistent quality throughout the construction process, reducing variability and improving overall

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- performance.
- Minimize Costs: By preventing failures and reducing rework, quality control and inspection can save money and avoid costly delays.

2. Steel



A. 2.1. Definition



Definition

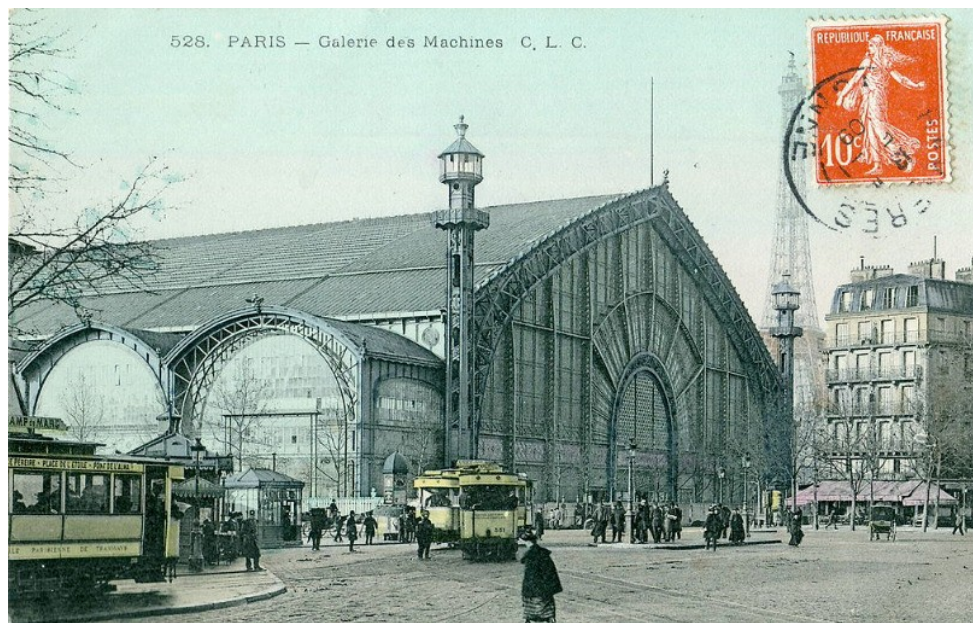
Steel is an alloy of iron and carbon, typically containing between 0.2% and 2.1% carbon by weight. Other elements, such as manganese, phosphorus, sulfur, silicon, and chromium, may also be present in small amounts. Steel is used in a wide variety of applications in architecture, from structural supports to aesthetic accents. It is an incredibly strong and durable material, making it an ideal choice for a variety of building projects. Steel is also incredibly versatile, allowing it to be formed and shaped into almost any shape or size.

Steel has been used in architecture for centuries. The use of iron in construction dates back to antiquity, with early civilizations employing it for tools, weapons, and decorative elements. However, it was during the Industrial Revolution that iron began to make its mark on architecture. The development of more efficient iron production methods and the introduction of cast iron in the 18th century opened up new possibilities for structural applications.

Cast iron's ability to be shaped into intricate forms made it ideal for decorative elements, while its strength allowed for its use in structural components like columns, beams, and arches. Notable examples of early iron-framed buildings include the Crystal Palace in London (1851)



and the Galerie des Machines in Paris (1889), both showcasing the potential of iron in large-scale construction.



The late 19th and early 20th centuries witnessed a surge in steel-framed construction, particularly in the United States. The Home Insurance Building in Chicago (1885)



Notable examples of contemporary steel-framed buildings include the Burj Khalifa in Dubai (2010).





B. 2.2. Classification, mechanical properties and behavior of steel

2.2.1. Classification of steel

Based on its composition and properties, steel is classified into various categories:

1. Carbon Steel: The most common type of steel, containing primarily iron and carbon. It is further classified into:
 - Low-carbon steel (<0.3% carbon): Soft, ductile, and easy to weld.
 - Medium-carbon steel (0.3%-0.6% carbon): Stronger and harder than low-carbon steel, but less ductile.
 - High-carbon steel (>0.6% carbon): Very strong and hard, but less ductile and more brittle.
2. Alloy Steel: Contains additional elements, such as chromium, nickel, molybdenum, or vanadium, to enhance specific properties like strength, corrosion resistance, or heat resistance.
3. Stainless Steel: Contains a minimum of 11% chromium, making it resistant to rust and corrosion. It is widely used in applications where hygiene and appearance are critical, such as kitchen appliances, medical equipment, and architectural components.
4. Tool Steel: Specially formulated for cutting and shaping other materials. It is characterized by its high hardness and wear resistance.

The selection of the appropriate type of steel for a specific application depends on several factors, including:

- Required mechanical properties (strength, ductility, hardness, toughness)
- Environmental conditions (corrosion, temperature, radiation)
- Fabrication processes (welding, forging, casting)

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- Cost considerations

Engineers and designers carefully consider these factors to choose the steel grade that best meets the performance and economic requirements of the application.

2.2.2. Mechanical properties of steel

The mechanical properties determine how steel behaves under various loading conditions and are crucial for its applications in construction, manufacturing, and other industries.

- **Strength:** Steel is one of the strongest materials, with a high tensile strength that allows it to withstand significant forces without breaking. This property makes steel essential for structural applications, such as buildings, bridges, and machinery.
- **Ductility:** Steel is ductile, meaning it can deform under stress without breaking. This property allows steel to be shaped into various forms, such as beams, rods, and wires. Ductility is particularly important in applications where steel is subjected to bending, twisting, or other deformations.
- **Malleability:** Steel is malleable, meaning it can be hammered or rolled into thin sheets without cracking. This property makes steel suitable for applications where thin sections are required, such as car bodies, appliances, and packaging.
- **Elasticity:** Steel is elastic within a certain stress range, meaning it can return to its original shape after being deformed. This property is crucial for applications where steel is subjected to cyclic loading, such as springs, shock absorbers, and machine parts.
- **Toughness:** Steel is tough, meaning it can absorb energy before breaking. This property is important for applications where steel is subjected to impact or sudden loading, such as protective armor, tools, and automotive components.
- **Fatigue Strength:** Steel can withstand repeated loading cycles without failing prematurely. This property is crucial for applications where steel is subjected to cyclic stresses, such as aircraft components, machinery parts, and bridges.
- **Hardness:** Steel can be hardened through various heat treatment processes to increase its resistance to wear and abrasion. This property is important for applications where steel is subjected to friction and wear, such as cutting tools, bearings, and gears.
- **Creep Resistance:** Steel can maintain its strength and shape at high temperatures, but it exhibits creep under prolonged stress at elevated temperatures. This property is important for applications where steel is used in high-temperature environments, such as boilers, turbines, and nuclear reactors.

The mechanical properties of steel are influenced by various factors, including:

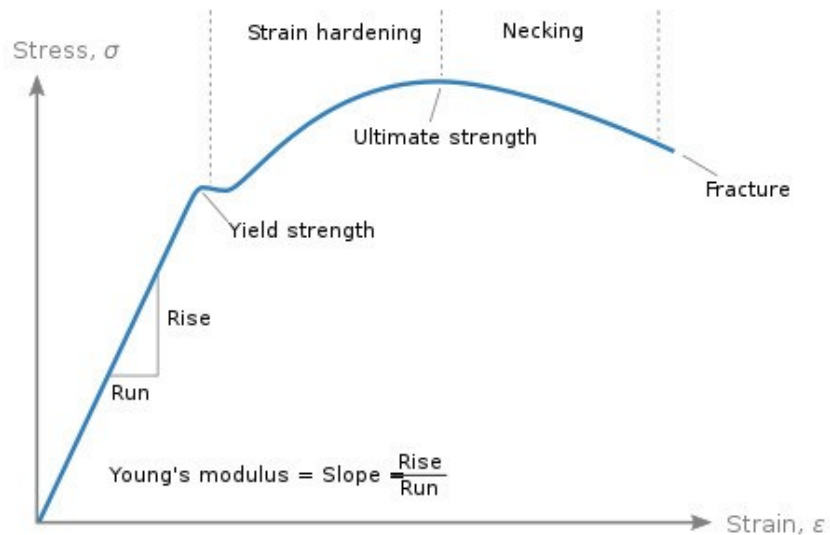
- **Composition:** The chemical composition of steel, particularly the carbon content, significantly impacts its strength, ductility, and hardness.
- **Heat Treatment:** Heat treatment processes, such as quenching and tempering, can alter the microstructure of steel, modifying its mechanical properties.
- **Manufacturing Processes:** The manufacturing processes used to produce steel, such as rolling, forging, and casting, can affect its grain structure and, consequently, its mechanical properties.

2.2.3. Behavior of steel

The stress-strain relationship of steel is a fundamental aspect of understanding its

behavior under various loading conditions. It plays a crucial role in engineering and design, enabling engineers to predict the performance of steel structures and components under different stresses.

The stress-strain curve for steel typically exhibits a nonlinear relationship, with distinct stages representing different phases of deformation and behavior (see the following figure):



C. 2.3. International codes

Several major international codes of steel design are widely recognized and used globally:

- **Eurocode 3 (EC3): Design of steel structures**

Developed and maintained by the European Committee for Standardization (CEN), EC3 is the most widely used code for steel design in Europe and many other countries. It covers various aspects of steel design, including material properties, structural analysis, member design, connections, and fire design.

- **American Institute of Steel Construction (AISC): Specification for Structural Steel Buildings (ANSI/AISC 360)**

Published by the American Institute of Steel Construction (AISC), AISC 360 is the primary code for steel design in the United States. It provides comprehensive guidelines for the design of steel buildings, including load combinations, member design, connections, and fire resistance.

D. 2.4. Quality Control Measures for Steel in Buildings

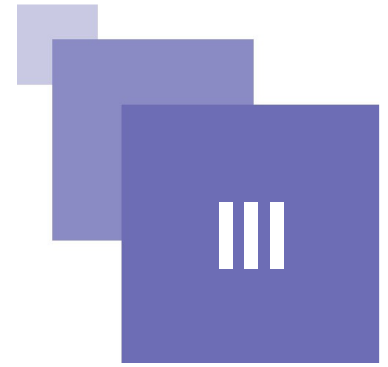
- **Material Testing:** Steel materials are subjected to various tests to verify their

2. Steel

chemical composition, mechanical properties, and dimensional accuracy. These tests ensure that the steel meets the specified grade and is suitable for the intended application.

- **Fabrication Inspection:** Fabrication processes, such as welding, cutting, and bending, are carefully inspected to ensure that they are performed in accordance with established procedures and standards. This includes checking welding qualifications, weld integrity, and overall workmanship.
- **Erection Inspection:** The erection of steel structures is closely monitored to ensure that the components are properly aligned, plumb, and level. Bolted connections are checked for tightness and proper torque, and welds are inspected for any defects.
- **Non-Destructive Testing (NDT):** NDT methods, such as ultrasonic testing, radiographic testing, and magnetic particle inspection, are employed to detect internal flaws or defects in steel components without causing damage. These methods are particularly useful for inspecting welds and critical areas of the structure.
- **Documentation and Reporting:** Detailed records of all QC and inspection activities are maintained, including test results, inspection reports, and non-destructive testing findings. This documentation provides a comprehensive history of the construction process and facilitates any necessary corrective actions.

3. Concrete vs Steel



A. Comparing Concrete and Steel

Property	Concrete	Steel
Strength	High compressive strength	High tensile strength Good compression strength, but slender bars will buckle
Ductility	Brittle	Ductile
Formability	Formability depends on the type of concrete	Formable
Spanning ability	Limited spanning ability	Can span large distances
Prefabrication	Prefabrication is more difficult	Can be easily prefabricated
Recyclability	Not as recyclable as steel	Can be recycled
Fire resistance	Fire resistant	Not fire resistant
Durability	Durable in most environments	Durable in most environments
Thermal mass	High thermal mass	Low thermal mass
Cost	Relatively inexpensive	Relatively expensive

The choice between steel and concrete depends on the specific requirements of the project. Architects and structural engineers must carefully consider the properties of each material, the desired aesthetics of the structure, the budget, and the environmental impact.

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