Chapter 28: Steel & Aluminum – Types of Steel and Manufacturing

Introduction

Steel and aluminum are two of the most essential and widely used metals in civil engineering and construction. Their combination of strength, ductility, corrosion resistance, and versatility makes them suitable for a wide variety of structural and non-structural applications. Understanding the different types of steel and the methods involved in their manufacturing is crucial for civil engineers involved in materials selection, structural design, and quality control. This chapter focuses on the classification of steel, the processes used in steel and aluminum production, and their significance in engineering applications.

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1. Steel: Classification and Properties

Steel is an alloy primarily composed of iron and carbon (usually less than 2%), with small amounts of other alloying elements. The properties of steel can be tailored through its composition and processing.

1.1 Classification of Steel

Steel can be classified in several ways:

A. Based on Carbon Content

1. **Low Carbon Steel (Mild Steel)**
    - Carbon content: up to 0.25%
    - Properties: Ductile, malleable, easily weldable, low tensile strength
    - Applications: Beams, channels, sheets, pipes, construction works
2. **Medium Carbon Steel**
    - Carbon content: 0.25% to 0.60%
    - Properties: Stronger than mild steel, less ductile, better wear resistance
    - Applications: Rail tracks, crankshafts, gears, heavy-duty machinery
3. **High Carbon Steel**

- Carbon content: 0.60% to 1.4%
- Properties: Very strong, brittle, difficult to weld
- Applications: Cutting tools, springs, high-strength wires

B. Based on Alloying Elements

1. **Plain Carbon Steel** – Contains carbon as the main alloying element
2. **Alloy Steel** – Contains additional elements like manganese, nickel, chromium, vanadium, etc.
    - Improves strength, hardness, corrosion resistance, and toughness

C. Based on Method of Manufacturing

1. **Killed Steel** – Fully deoxidized during manufacturing
    - Uniform composition, fewer blowholes
2. **Semi-killed Steel** – Partially deoxidized
    - Balanced properties
3. **Rimmed Steel** – Poorly deoxidized
    - Used for applications where surface finish is more important than strength

D. Based on Microstructure

1. **Ferritic Steel** – Magnetic, good ductility
2. **Austenitic Steel** – Non-magnetic, high corrosion resistance
3. **Martensitic Steel** – Very hard and brittle, can be tempered
4. **Pearlitic Steel** – High strength, moderate ductility

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2. Manufacturing of Steel

Steel production generally involves two main processes:

2.1 Primary Steelmaking

This refers to the extraction of steel from iron ore or scrap:

A. Blast Furnace – Basic Oxygen Furnace (BF-BOF) Process

1. **Raw Materials**: Iron ore, coke, limestone

2. **Process**:
    - Iron ore is reduced in a **blast furnace** to produce **molten pig iron**
    - Molten pig iron is transferred to a **basic oxygen furnace**
    - High-purity oxygen is blown through the molten iron to remove impurities (carbon, sulfur, phosphorus)
    - Alloying elements are added
3. **Output**: Primary steel (carbon steel or alloy steel)

B. Electric Arc Furnace (EAF) Process

1. **Raw Materials**: Steel scrap, sometimes DRI (Direct Reduced Iron)
2. **Process**:
    - Electric arcs melt the scrap
    - Oxygen is injected to remove impurities
    - Alloying elements are added
3. **Advantages**:
    - Energy efficient
    - Ideal for recycling steel
    - Lower emissions

2.2 Secondary Steelmaking (Refining)

Involves fine-tuning the chemical composition and temperature:

- **Processes**: Ladle metallurgy, vacuum degassing, argon oxygen decarburization
- **Purpose**: Remove non-metallic inclusions, adjust composition

2.3 Steel Casting and Forming

After refining, the molten steel is cast into shapes:

- **Ingot Casting**: For large sections
- **Continuous Casting**: More efficient, used for billets, blooms, slabs
- **Rolling**: Hot or cold rolling processes to form sheets, bars, wires

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3. Aluminum: Properties and Types

Aluminum is a lightweight, corrosion-resistant metal, highly valued in construction for window frames, cladding, doors, and roofing.

3.1 Properties of Aluminum

- Low density (one-third that of steel)
- Excellent corrosion resistance due to natural oxide layer
- High thermal and electrical conductivity
- Good strength-to-weight ratio
- Easy to extrude and shape

3.2 Types of Aluminum

A. Pure Aluminum (1000 series)

- Minimum 99% aluminum
- High corrosion resistance
- Low strength
- Used where formability and corrosion resistance are more important than strength

B. Aluminum Alloys

1. **Wrought Alloys** (Work-hardened)
    - **2xxx Series (Al-Cu)** – High strength, low corrosion resistance
    - **3xxx Series (Al-Mn)** – Moderate strength, good corrosion resistance
    - **5xxx Series (Al-Mg)** – Good weldability, high corrosion resistance
    - **6xxx Series (Al-Mg-Si)** – Medium strength, good corrosion resistance, used in structural applications
    - **7xxx Series (Al-Zn)** – Very high strength, used in aerospace
2. **Cast Alloys** – Lower ductility, good castability, used in architectural components

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4. Manufacturing of Aluminum

4.1 Extraction – Bayer Process

1. **Bauxite Ore** is the primary raw material

2. **Crushing and Grinding** – Increases surface area
3. **Digestion with Sodium Hydroxide** – Forms soluble sodium aluminate
4. **Settling and Clarification** – Removes red mud (impurities)
5. **Precipitation** – Aluminum hydroxide is precipitated
6. **Calcination** – Heated in rotary kilns to form **alumina (Al_2O_3)**

4.2 Reduction – Hall–Héroult Process

1. **Electrolytic Reduction of Alumina**:
    - Dissolved in molten cryolite (Na_3AlF_6)
    - Electrolysis in carbon-lined cells
    - Aluminum is deposited at cathode, oxygen at anode (which burns off)

4.3 Aluminum Forming and Fabrication

- **Rolling**: For sheets, foils
- **Extrusion**: For hollow shapes, channels, pipes
- **Casting**: Sand casting, die casting
- **Forging**: For load-bearing components

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5. Applications in Civil Engineering

Steel

- Structural frames
- Reinforcement in concrete (rebar)
- Roofing and cladding
- Pipes and tubes
- Bridges, towers, industrial sheds

Aluminum

- Window and door frames
- Curtain wall systems
- Roofing sheets
- Cladding and facades
- Electrical transmission lines

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6. Corrosion of Steel and Aluminum in Civil Structures

Understanding the corrosion behavior of metals is crucial for ensuring the longevity and safety of civil structures.

6.1 Corrosion of Steel

Steel is highly susceptible to corrosion when exposed to moisture, oxygen, and pollutants.

Types of Steel Corrosion

1. **Uniform Corrosion**
    - Occurs evenly over the surface
    - Common in atmospheric exposure
2. **Galvanic Corrosion**
    - Occurs when two dissimilar metals are in contact in a corrosive environment
    - Steel connected to aluminum or copper can corrode faster
3. **Pitting Corrosion**
    - Localized corrosion leading to small pits
    - Often occurs due to chloride ions (e.g., in marine environments)
4. **Crevice Corrosion**
    - Occurs in shielded areas where moisture is trapped, e.g., joints and overlaps

Corrosion Protection Techniques

- **Protective Coatings**: Paint, bituminous coating, epoxy
- **Cathodic Protection**: Sacrificial anodes or impressed current
- **Galvanization**: Coating with zinc
- **Use of Corrosion-Resistant Steel**: e.g., weathering steel (Corten)

6.2 Corrosion of Aluminum

Aluminum forms a passive oxide layer (Al_2O_3) naturally, which protects it from further corrosion. However, in certain environments (e.g., alkaline, acidic, or saline), this protection may fail.

Common Aluminum Corrosion Forms

- **Pitting Corrosion** in chloride-rich environments

- **Galvanic Corrosion** when in contact with more noble metals
- **Filiform Corrosion** beneath coatings or paints

Prevention Measures

- **Anodizing**: Thickens oxide layer
- **Powder Coating**: Durable external finish
- **Proper Design**: Avoiding moisture traps and dissimilar metal contact

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7. Mechanical Testing of Steel and Aluminum

To ensure fitness for structural applications, both materials undergo rigorous mechanical testing.

7.1 Tensile Test

- **Objective**: To determine ultimate tensile strength, yield strength, and elongation
- **Equipment**: Universal Testing Machine (UTM)
- **Key Parameters**:
    - Yield stress (σy)
    - Ultimate stress (σu)
    - % Elongation
    - Young's Modulus (E)

7.2 Hardness Test

- Measures resistance to indentation
- Common methods:
    - Brinell Hardness Test (BHN) – used for steel
    - Rockwell and Vickers – used for precise applications

7.3 Impact Test

- Determines toughness or energy absorption during fracture
- **Charpy and Izod** tests are common
- Crucial for evaluating ductile-to-brittle transition in steel

7.4 Fatigue and Creep Testing

- **Fatigue**: Resistance to failure under repeated loading
- **Creep**: Deformation under sustained load and temperature over time

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8. Comparison Between Steel and Aluminum for Construction

Property	Steel	Aluminum
Density	~7.85 g/cm³	~2.7 g/cm³
Strength	Very high	Moderate to high
Corrosion Resistance	Moderate (unless protected)	High (with oxide layer)
Cost	Less expensive	More expensive
Thermal Conductivity	Moderate	High
Ease of Fabrication	Good	Excellent
Weldability	Excellent (Mild Steel)	Good but requires care
Maintenance	Needs coatings, inspection	Low, mostly self-passivating

9. Steel and Aluminum Codes and Standards (India and International)

9.1 Indian Standards (IS Codes)

- **IS 2062**: Hot Rolled Low, Medium, and High Tensile Structural Steel
- **IS 1786**: High Strength Deformed Steel Bars for Concrete Reinforcement
- **IS 800**: General Construction in Steel – Code of Practice
- **IS 733 / IS 1285**: Aluminum alloy extruded products
- **IS 737**: Wrought Aluminum and Aluminum Alloy Sheet and Strip

9.2 International Standards

- **ASTM A36 / A992**: Structural steel specifications (USA)
- **EN 10025**: European standard for structural steel
- **BS EN 485**: British standard for aluminum products

- **AA Standards**: Aluminum Association (USA) designations and specs

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10. Sustainable and Modern Developments

10.1 Green Steel

- Produced using hydrogen or renewable energy instead of coke
- Minimizes CO_2 emissions
- Technologies like DRI (Direct Reduced Iron) using green hydrogen

10.2 Recycled Aluminum

- Aluminum is 100% recyclable with minimal loss of properties
- Saves 95% energy compared to primary production

10.3 Composite Use in Construction

- Use of **steel-aluminum hybrids** in facades and bridges
- Combination improves strength-to-weight ratio and aesthetics

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