Material science and engineering

by William D. Callister. JR · Language: EN

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Overview

William D. Callister, Jr.'s "Material Science and Engineering: An Introduction" is a foundational textbook that systematically introduces the principles governing the structure, properties, processing, and performance of materials. It serves as a comprehensive guide for understanding the fundamental science behind engineering materials, emphasizing the crucial interrelationships between these four pillars. The book begins by establishing atomic structure and bonding as the basis for all material behavior, then progressively builds upon this foundation to explore crystalline structures, imperfections, and diffusion processes.

The text delves into the mechanical, thermal, electrical, and optical properties of materials, explaining how these characteristics arise from their atomic and microstructural arrangements. It provides detailed coverage of the major material classes—metals, ceramics, polymers, and composites—discussing their unique properties, typical processing methods, and diverse applications. Callister's approach is highly pedagogical, featuring numerous examples, illustrations, and problem sets designed to make complex concepts accessible to undergraduate students in engineering and related disciplines.

This book is essential for anyone seeking a robust understanding of how materials are designed, selected, and utilized in various engineering contexts. It equips readers with the knowledge to predict material behavior, troubleshoot failures, and innovate new material solutions, making it a cornerstone resource for both academic study and professional practice in materials engineering.

Key Takeaways

- Material properties are fundamentally determined by their atomic structure and the nature of their interatomic bonds.
- Understanding crystal structures and the presence of imperfections is crucial for predicting and controlling material behavior.
- Diffusion processes are essential for many material treatments and for understanding long-term material degradation mechanisms.
- Mechanical properties like strength, ductility, and toughness are critical considerations for material selection in structural applications.

• Metals, ceramics, polymers, and composites each possess distinct properties and processing challenges due to their unique microstructures.

• The performance of a material in a given application is a direct consequence of its structure-property-processing relationship.

• Engineers must consider environmental factors and degradation mechanisms when designing with materials to ensure long-term reliability.

Chapter Summaries

Chapter 1: Introduction

This foundational chapter introduces the field of materials science and engineering, emphasizing the critical interrelationship between a material's structure, processing, properties, and performance. It categorizes materials into major classes—metals, ceramics, polymers, and composites—and briefly outlines their characteristic features and typical applications. The chapter highlights the historical significance of materials development, from the Stone Age to the Silicon Age, and sets the stage for understanding how engineers design and select materials to meet specific functional requirements and address contemporary challenges.

Chapter 2: Atomic Structure and Interatomic Bonding

This chapter delves into the fundamental atomic structure of materials, covering concepts such as electrons, protons, neutrons, and electron configurations. It thoroughly explains the various types of primary interatomic bonds: ionic, covalent, and metallic, detailing the mechanisms of electron transfer or sharing involved. Additionally, it discusses secondary bonding forces, including van der Waals forces and hydrogen bonding. The chapter elucidates how the nature and strength of these bonds directly influence macroscopic material properties like melting temperature, elastic modulus, and thermal expansion coefficient.

Chapter 3: The Structure of Crystalline Solids

Focusing on the ordered arrangement of atoms in crystalline materials, this chapter introduces key concepts like unit cells, crystal systems (e.g., face-centered cubic, body-centered cubic, hexagonal close-packed), and crystallographic directions and planes using Miller indices. It explains how to determine atomic packing factors and theoretical densities. The chapter also differentiates between single crystals and polycrystalline materials, discussing the characteristics of grain boundaries and the phenomenon of polymorphism and allotropy in various elements and compounds.

Chapter 4: Imperfections in Solids

This chapter explores deviations from perfect crystal structures, which are crucial for understanding material behavior. It categorizes imperfections into point defects (vacancies, interstitial atoms, substitutional impurities), linear defects (dislocations, including edge, screw,

and mixed types), and planar defects (grain boundaries, twin boundaries, stacking faults). The chapter emphasizes the profound impact of these imperfections on material properties, particularly mechanical strength, electrical conductivity, and diffusion rates, providing a basis for subsequent discussions on strengthening mechanisms.

Chapter 5: Diffusion

This chapter explains the atomic mechanisms of mass transport in solid materials. It introduces Fick's first and second laws of diffusion, distinguishing between steady-state and non-steady-state diffusion processes. Key diffusion mechanisms, such as vacancy diffusion and interstitial diffusion, are detailed. The chapter also discusses factors influencing diffusion rates, including temperature, the type of diffusing species, and the host material, providing practical examples like the carburization of steel to enhance surface hardness.

Chapter 6: Mechanical Properties of Metals

This chapter introduces fundamental mechanical properties and their experimental determination. It covers concepts of stress and strain, elastic and plastic deformation, and key properties like yield strength, tensile strength, ductility, resilience, and toughness. The chapter differentiates between engineering stress-strain and true stress-strain curves. It also details various hardness testing methods, including Brinell, Rockwell, and Vickers, explaining how these tests provide insights into a material's resistance to localized plastic deformation.

Chapter 7: Dislocations and Strengthening Mechanisms

Building on the concept of dislocations, this chapter explains their pivotal role in the plastic deformation of crystalline materials. It describes slip systems and the movement of dislocations under applied stress. The chapter then details various mechanisms used to strengthen metals: grain size reduction, solid-solution strengthening, strain hardening (cold work), and precipitation hardening. Each mechanism is explained in terms of how it impedes dislocation motion, thereby increasing the material's resistance to plastic deformation.

Chapter 8: Failure

This chapter examines the different modes by which materials fail under stress. It covers fracture, distinguishing between ductile and brittle fracture, and discusses impact fracture using Charpy and Izod tests. A significant portion is dedicated to fatigue, explaining S-N curves, fatigue limits, and the stages of crack initiation and propagation. The chapter also addresses creep, which is time-dependent deformation at elevated temperatures, and discusses various factors influencing these failure modes and strategies for prevention.

Chapter 9: Phase Diagrams

This chapter introduces the concept of phase diagrams as graphical representations showing the equilibrium phases present in a material system at different temperatures, pressures, and compositions. It focuses on binary isomorphous systems (e.g., copper-nickel) and eutectic

systems (e.g., lead-tin, iron-carbon). The chapter explains how to interpret these diagrams, including the use of the lever rule to determine phase amounts and compositions, and how microstructures evolve during cooling from the liquid state.

Chapter 10: Phase Transformations

This chapter delves into the kinetics of phase transformations, explaining the processes of nucleation and growth. It specifically focuses on transformations in steels, detailing the formation of pearlite, bainite, and martensite. The chapter introduces time-temperature-transformation (TTT) diagrams and continuous-cooling transformation (CCT) diagrams as essential tools for understanding and predicting the microstructures resulting from various heat treatments, such as annealing, normalizing, quenching, and tempering.

Chapter 11: Processing of Metal Alloys

This chapter covers a range of techniques used to process metal alloys, linking processing methods to the resulting microstructure and properties. It discusses solidification processes and various casting methods (e.g., sand casting, die casting). Forming operations like forging, rolling, extrusion, and drawing are explained. The chapter also details different heat treatments (e.g., annealing, normalizing, hardening, tempering) and introduces powder metallurgy, emphasizing how each process influences the final mechanical and physical characteristics of metal components.

Chapter 12: Ceramics: Structure, Properties, and Applications

This chapter introduces ceramic materials, highlighting their predominantly ionic and covalent bonding and diverse crystal structures (e.g., AX, AmXp, ABX3). It discusses their characteristic properties, including high hardness, brittleness, high melting points, and excellent thermal and electrical insulation. Common processing techniques like powder pressing, slip casting, and sintering are covered. The chapter explores various applications, such as refractories, abrasives, glasses, and advanced ceramics in electronics and biomedical fields.

Chapter 13: Polymers: Structure, Properties, and Applications

This chapter explores the structure and properties of polymeric materials. It covers molecular weight, degree of polymerization, and various molecular structures (linear, branched, crosslinked, network). The distinction between thermoplastic and thermosetting polymers is made, along with discussions on crystallinity, glass transition temperature, and melting temperature. The chapter details the mechanical properties of polymers and provides an overview of common polymer types (e.g., polyethylene, PVC, nylon) and their wide range of applications.

Chapter 14: Composites

This chapter defines composite materials as combinations of two or more distinct phases, resulting in properties superior to those of the individual components. It classifies composites

into particulate, fiber-reinforced, and structural types. A significant focus is placed on fiber-reinforced composites, discussing the roles of the matrix and reinforcement phases, fiber alignment, and the rule of mixtures for predicting composite properties. Specific examples like fiberglass, carbon fiber composites, and their applications in aerospace and automotive industries are explored.

Chapter 15: Corrosion and Degradation of Materials

This chapter addresses the deterioration of materials due to environmental interaction. It primarily focuses on electrochemical corrosion mechanisms in metals, detailing types such as galvanic corrosion, pitting, crevice corrosion, and stress corrosion cracking. The chapter also discusses the degradation of ceramic and polymeric materials. Various methods for corrosion prevention are covered, including protective coatings, cathodic protection, anodic protection, and the use of inhibitors, emphasizing the importance of material selection and design in mitigating degradation.

Chapter 16: Electrical Properties

This chapter explains the electrical behavior of materials. It covers fundamental concepts like electrical conductivity, resistivity, and Ohm's law. The chapter delves into electronic band structure to differentiate between conductors, semiconductors (intrinsic, extrinsic, n-type, p-type), and insulators. It also introduces dielectric materials, explaining concepts like dielectric constant and dielectric breakdown, and briefly touches upon ferroelectricity and piezoelectricity, highlighting their applications in electronic devices.

Chapter 17: Thermal Properties

This chapter focuses on how materials respond to thermal energy. It covers key thermal properties such as heat capacity, thermal expansion, and thermal conductivity. The mechanisms of heat conduction in metals, ceramics, and polymers are explained, relating them to atomic and molecular structures. The chapter also discusses thermal stresses that arise from temperature changes and the concept of thermal shock resistance, which is critical for materials used in high-temperature applications.

Chapter 18: Magnetic Properties

This chapter introduces the origins of magnetism in materials, explaining how atomic magnetic moments lead to macroscopic magnetic behavior. It covers different types of magnetism: diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, and ferrimagnetism. Key concepts like magnetic domains, hysteresis loops, saturation magnetization, and coercivity are discussed. The chapter differentiates between soft and hard magnetic materials and explores their diverse applications in transformers, permanent magnets, and data storage devices.

Chapter 19: Optical Properties

This chapter explores the interaction of light with materials. It covers fundamental optical phenomena such as refraction, reflection, absorption, and transmission. The chapter explains how electronic and ionic polarization contribute to a material's optical behavior, influencing properties like color, transparency, and opacity. It also discusses luminescence, phosphorescence, and the principles behind lasers, providing examples of optical materials used in lenses, optical fibers, and display technologies.

Chapter 20: Materials Selection and Design Considerations

This concluding chapter integrates the knowledge gained throughout the book, focusing on the systematic approach to selecting materials for specific engineering applications. It emphasizes considering a multitude of factors, including required properties, cost, processing feasibility, environmental impact, and lifecycle assessment. The chapter often introduces tools like Ashby charts (materials selection charts) to graphically compare and select materials based on performance indices, guiding engineers in making informed decisions for optimal design.

Themes

- Structure-Property Relationship
- Material Selection
- Processing Influence
- Material Degradation
- Atomic-Scale Behavior
- Engineering Applications

Frequently Asked Questions

What is Material science and engineering about?

It's a comprehensive textbook covering the fundamental principles of materials science and engineering. It explores the relationship between the atomic structure, processing, properties, and performance of various materials, including metals, ceramics, polymers, and composites. The book aims to provide a foundational understanding for engineers to select and design materials effectively.

Is Material science and engineering worth reading?

Yes, it is widely considered a cornerstone textbook for anyone studying materials science, mechanical engineering, or related fields. Its clear explanations, numerous examples, and problem sets make complex concepts accessible. It's an essential resource for building a strong foundation in the subject.

Who should read Material science and engineering?

Undergraduate students in materials science, mechanical engineering, chemical engineering, civil engineering, and electrical engineering will find this book invaluable. It is also useful for practicing engineers seeking to refresh their knowledge or understand material fundamentals.

How long does it take to read Material science and engineering?

Given its depth and comprehensive nature, reading the entire textbook thoroughly could take anywhere from 40 to 80 hours, depending on the reader's prior knowledge and study pace. Many readers will focus on specific chapters relevant to their courses.

Best Quotes

“Materials science involves investigating the relationships between the structures and properties of materials.”

Introduction

This line introduces the core discipline of materials science, emphasizing the fundamental link between a material's internal arrangement (structure) and its observable characteristics (properties). It sets the stage for the entire book's approach.

“Materials engineering, on the other hand, is, on the basis of these structure-property correlations, designing or engineering the structure of a material to produce a predetermined set of properties.”

Introduction

This defines materials engineering as the application side of materials science. It highlights the goal of manipulating material structure to achieve desired properties for specific applications, a key theme throughout the book.

“The properties of a material depend on its structure, processing, and performance.”

Introduction

This fundamental principle, often called the 'materials science and engineering paradigm,' underscores the interconnectedness of how a material is made, its internal arrangement, its characteristics, and its ultimate application. It's central to the book's framework.

“A unit cell is the smallest group of atoms or molecules whose repetition in space in three dimensions produces the crystal.”

The Structure of Crystalline Solids

This defines the fundamental building block of crystalline structures. Understanding unit cells is crucial for describing and analyzing the atomic arrangement and symmetry of solid materials,

which in turn dictates many properties.

“Dislocations are linear or one-dimensional defects around which some of the atoms are misaligned.”

Imperfections in Solids

This defines dislocations, which are fundamental line defects in crystalline materials. Their movement is the primary mechanism of plastic deformation in metals, making them critical to understanding mechanical behavior.

“Diffusion is the phenomenon of material transport by atomic motion.”

Diffusion

This defines diffusion, a critical process in materials science where atoms move within a material. It's essential for understanding phenomena like heat treatment, phase transformations, and material degradation.

“Stress is defined as the internal resistance of a material to an externally applied load.”

Mechanical Properties of Metals

This defines stress, a fundamental concept in mechanics of materials. It quantifies the internal forces acting within a deformable body, crucial for analyzing how materials respond to external forces.

“Strain is a measure of the deformation of a material in response to an applied stress.”

Mechanical Properties of Metals

This defines strain, another fundamental mechanical concept. It quantifies the degree of deformation a material undergoes, providing a normalized measure independent of the material's original dimensions.

“Elastic deformation is nonpermanent, meaning that when the applied load is released, the material returns to its original shape.”

Mechanical Properties of Metals

This describes elastic deformation, a reversible process where a material temporarily changes shape under stress but recovers completely upon load removal. It's governed by Hooke's Law within the elastic limit.

“Plastic deformation is permanent, meaning that the material does not return to its original shape after the load is removed.”

This describes plastic deformation, an irreversible process where a material undergoes permanent shape change even after the applied load is removed. It involves atomic bond breaking and reforming, often via dislocation motion.

“Fracture is the separation of a body into two or more pieces in response to an imposed stress.”

Fracture Mechanics

This defines fracture, a critical failure mechanism where a material breaks apart. Understanding fracture types (ductile vs. brittle) is essential for material selection and design to prevent catastrophic failures.

“Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses.”

Fatigue

This defines fatigue, a common failure mode in components under cyclic loading, even at stresses below the yield strength. It's crucial for designing parts that endure repeated stress cycles without sudden failure.

“Creep is the time-dependent plastic deformation of materials under constant load at elevated temperatures.”

Creep

This defines creep, a deformation mechanism significant at high temperatures where materials slowly deform over time under constant stress. It's critical for designing components in high-temperature applications like jet engines.

“Corrosion is the destructive attack of a material by reaction with its environment.”

Corrosion and Degradation of Materials

This defines corrosion, a degradation process where materials react with their surroundings, leading to deterioration of properties. Understanding and preventing corrosion is vital for extending the lifespan of engineered structures.

“Polymers are large molecules (macromolecules) formed by the covalent bonding of repeating structural units called monomers.”

Polymer Structures

This defines polymers, a major class of materials characterized by their long chain-like molecular structures. Their properties are highly dependent on molecular weight, chain architecture, and bonding.

“Ceramics are inorganic, nonmetallic materials often characterized by ionic or covalent bonding.”

Structure and Properties of Ceramics

This defines ceramics, a class of materials known for high hardness, high melting points, and chemical inertness. Their properties stem from strong ionic or covalent bonds and often complex crystal structures.

“Composites are materials composed of two or more constituent materials with significantly different physical or chemical properties.”

Composites

This defines composites, engineered materials designed to achieve superior properties by combining different constituent materials. The goal is often to leverage the best attributes of each component.

“Semiconductors are materials that have electrical conductivities intermediate between those of conductors and insulators.”

Electrical Properties

This defines semiconductors, a class of materials whose electrical conductivity can be precisely controlled. They are fundamental to modern electronics, forming the basis of transistors and integrated circuits.

Questions & Answers

What is the fundamental relationship between structure, processing, properties, and performance in materials science and engineering?

The book emphasizes that these four components are intrinsically linked. A material's processing dictates its internal structure. This structure, in turn, determines the material's properties (e.g., strength, conductivity). Finally, these properties dictate how well the material will perform in a specific application. Materials scientists and engineers manipulate this cycle to design materials for desired performance.

Explain the primary types of atomic bonding and how they influence material properties.

The primary types are ionic, covalent, and metallic bonding. Ionic bonds involve electron transfer, forming strong, non-directional bonds, common in ceramics, leading to high melting

points and hardness. Covalent bonds involve electron sharing, also strong and directional, found in polymers and some ceramics, influencing their rigidity. Metallic bonds involve a 'sea' of delocalized electrons, leading to good electrical/thermal conductivity, ductility, and strength in metals.

What is the significance of the stress-strain curve for engineering materials?

The stress-strain curve is a fundamental graphical representation of a material's mechanical behavior under load. It provides critical information such as elastic modulus (stiffness), yield strength (onset of plastic deformation), tensile strength (maximum stress before necking), and ductility (amount of plastic deformation before fracture). Engineers use this curve for material selection, design, and predicting how a component will behave under various loading conditions.

Describe the role of dislocations in the plastic deformation of metals.

Dislocations are line defects in the crystal lattice of metals. Plastic deformation in metals primarily occurs through the movement of these dislocations. Under applied shear stress, dislocations glide along specific crystallographic planes, causing planes of atoms to permanently slip past one another. This process, known as slip, allows metals to deform plastically without fracturing, contributing to their ductility.

How does temperature affect the diffusion rate in solids?

Temperature significantly increases the diffusion rate in solids. Diffusion is an atomic process that requires atoms to overcome an activation energy barrier to move from one lattice site to another. As temperature increases, atoms possess more thermal energy, leading to a higher frequency of atomic vibrations and a greater probability of overcoming this energy barrier. This results in faster atomic movement and, consequently, a higher diffusion coefficient.

What are the main strengthening mechanisms employed in metals?

Callister discusses several strengthening mechanisms. These include: 1) Grain size reduction, where smaller grains impede dislocation motion more effectively. 2) Solid-solution strengthening, where impurity atoms create lattice distortions that hinder dislocation movement. 3) Strain hardening (cold work), which increases dislocation density, causing them to entangle and resist further motion. 4) Precipitation hardening, where fine, uniformly dispersed second-phase particles act as obstacles to dislocation movement.

Explain the concept of phase diagrams and their utility in materials science.

Phase diagrams are graphical representations showing the equilibrium phases present in a material system as a function of temperature, pressure, and composition. They are invaluable tools for materials scientists and engineers. They allow for predicting phase transformations, determining the melting/solidification behavior of alloys, designing heat treatments to achieve desired microstructures, and understanding the solubility limits of different components in a mixture.

Compare and contrast ductile and brittle fracture.

Ductile fracture involves significant plastic deformation before failure, characterized by a 'cup-and-cone' fracture surface, high energy absorption, and slow crack propagation. Brittle fracture, conversely, occurs with little or no plastic deformation, often rapidly, and is characterized by a flat, shiny fracture surface (cleavage) and low energy absorption. Ductile materials 'warn' of failure, while brittle materials fail suddenly.

What are the general characteristics and typical applications of ceramic materials?

Ceramics are inorganic, nonmetallic materials, typically characterized by strong ionic or covalent bonds. They exhibit high hardness, high melting temperatures, chemical inertness, and good electrical and thermal insulation properties. However, they are generally brittle. Applications include refractories (furnace linings), abrasives, cutting tools, electrical insulators, biomaterials (implants), and advanced structural components in high-temperature environments.

How do semiconductors differ from conductors and insulators in terms of electrical conductivity?

Conductors (like metals) have high electrical conductivity due to a large number of free electrons. Insulators have very low conductivity because their electrons are tightly bound. Semiconductors have electrical conductivities intermediate between conductors and insulators. Crucially, their conductivity can be precisely controlled by temperature, doping with impurities (extrinsic semiconductors), or applying electric fields, making them essential for electronic devices.

What is the importance of material selection in engineering design?

Material selection is paramount in engineering design because the choice of material directly impacts a product's functionality, safety, cost, and lifespan. Engineers must consider a material's properties (mechanical, electrical, thermal, chemical), its processability, environmental factors, and economic viability to ensure the final product meets all design requirements and performs reliably under its intended operating conditions.

Describe the phenomenon of fatigue failure and methods to mitigate it.

Fatigue failure occurs when a material is subjected to repeated or cyclic stresses, even if those stresses are below the material's yield strength. It typically initiates at microscopic flaws and propagates as cracks, leading to sudden, catastrophic failure. Mitigation methods include reducing stress concentrations (e.g., by rounding corners), surface treatments (shot peening, carburizing) to induce compressive residual stresses, improving surface finish, and selecting materials with high fatigue strength.

What is creep, and in what types of applications is it a significant concern?

Creep is the time-dependent, permanent (plastic) deformation of materials under a constant applied load, typically at elevated temperatures. It's a diffusion-controlled process. Creep is a

significant concern in applications where components operate under sustained stress at high temperatures for extended periods, such as turbine blades in jet engines, nuclear reactor components, high-temperature furnace parts, and power plant steam pipes, where it can lead to eventual failure.

Explain the concept of a unit cell and its importance in crystallography.

A unit cell is the smallest repeating structural unit that, when stacked together in three dimensions, generates the entire crystal lattice. It defines the symmetry and atomic arrangement of a crystalline material. Its importance in crystallography lies in its ability to characterize the entire crystal structure using a minimal set of parameters (lattice parameters and interaxial angles), which is crucial for understanding and predicting material properties.

How do intrinsic and extrinsic semiconductors differ?

Intrinsic semiconductors are pure materials (e.g., pure silicon or germanium) whose electrical conductivity is solely due to thermally generated electron-hole pairs. Their conductivity is low and increases with temperature. Extrinsic semiconductors are intrinsic semiconductors that have been intentionally doped with impurities (e.g., phosphorus or boron in silicon). Doping significantly increases conductivity by introducing excess electrons (n-type) or holes (p-type), allowing for precise control of their electrical behavior.

What are composite materials, and what advantage do they offer over monolithic materials?

Composite materials are engineered materials made from two or more distinct constituent materials, often a matrix and a reinforcement, that retain their individual identities but combine to produce properties superior to those of the individual components. Their main advantage is the ability to tailor properties like high strength-to-weight ratio, stiffness, fatigue resistance, and corrosion resistance, which are not achievable with a single monolithic material. Examples include fiberglass and carbon fiber reinforced polymers.

Describe the process of annealing and its common purposes in metallurgy.

Annealing is a heat treatment process that involves heating a metal to a specific temperature, holding it there for a period, and then slowly cooling it. Its common purposes include relieving internal stresses caused by cold working or non-uniform cooling, increasing ductility and toughness, reducing hardness, refining grain structure, and improving machinability. It essentially reverses the effects of cold work and promotes a more stable, equilibrium microstructure.

What is the role of phase transformations in materials processing?

Phase transformations are critical in materials processing, especially in metallurgy, as they allow for the manipulation of a material's microstructure and, consequently, its properties. Heat treatments like annealing, quenching, and tempering rely on controlled phase transformations

(e.g., austenite to pearlite, bainite, or martensite in steel) to achieve desired combinations of strength, hardness, and ductility. Understanding these transformations is key to tailoring material performance.

How does grain size influence the mechanical properties of metals?

Grain size significantly influences the mechanical properties of metals, primarily through the Hall-Petch relationship. Smaller grain sizes generally lead to increased yield strength and hardness because grain boundaries act as barriers to dislocation motion. A larger total area of grain boundaries in fine-grained materials means dislocations encounter more obstacles, requiring higher stress to initiate and sustain plastic deformation. However, very fine grains can sometimes reduce ductility.

What are the main types of polymers, and how do their structures affect their properties?

The main types are thermoplastics, thermosets, and elastomers. Thermoplastics (e.g., polyethylene) consist of linear or branched chains, soften upon heating, and can be repeatedly melted and reformed. Thermosets (e.g., epoxy) form a rigid, cross-linked network during curing, are harder, stronger, and do not melt upon reheating. Elastomers (e.g., rubber) have lightly cross-linked chains, allowing for large, reversible elastic deformation. These structural differences dictate their processing and application.