Ch3

Short-range order - The regular and predictable arrangement of the atoms over a short distance - usually one or two atom spacings.

Long-range order (LRO) - A regular repetitive arrangement of atoms in a solid which extends over a very large distance.

Bose-Einstein condensate (BEC) - A newly experimentally verified state of a matter in which a group of atoms occupy the same quantum ground state

Amorphous materials - Materials, including glasses, that have no long-range order, or crystal structure.

Glasses - Solid, non-crystalline materials (typically derived from the molten state) that have only short-range atomic order.

Glass-ceramics - A family of materials typically derived from molten inorganic glasses and processed into crystalline materials with very fine grain size and improved mechanical properties.

Lattice - A collection of points that divide space into smaller equally sized segments.

Basis - A group of atoms associated with a lattice point.

Unit cell - A subdivision of the lattice that still retains the overall characteristics of the entire lattice.

Atomic radius - The apparent radius of an atom, typically calculated from the dimensions of the unit cell, using close-packed directions (depends upon coordination number).

Packing factor - The fraction of space in a unit cell occupied by atoms.

Allotropy - The characteristic of an element being able to exist in more than one crystal structure, depending on temperature and pressure.

Polymorphism - Compounds exhibiting more than one type of crystal structure.

Miller indices - A shorthand notation to describe certain crystallographic directions and planes in a material. Denoted by [ ] brackets. A negative number is represented by a bar over the number.

Directions of a form - Crystallographic directions that all have the same characteristics, although their ‘‘sense’’ is different. Denoted by h i brackets.

Repeat distance - The distance from one lattice point to the adjacent lattice point along a direction.

Linear density - The number of lattice points per unit length along a direction.

Packing fraction - The fraction of a direction (linear-packing fraction) or a plane (planar-packing factor) that is actually covered by atoms or ions.

Interstitial sites - Locations between the ‘‘normal’’ atoms or ions in a crystal into which another - usually different - atom or ion is placed. Typically, the size of this interstitial location is smaller than the atom or ion that is to be introduced.

Cubic site - An interstitial position that has a coordination number of eight. An atom or ion in the cubic site touches eight other atoms or ions.

Octahedral site - An interstitial position that has a coordination number of six. An atom or ion in the octahedral site touches six other atoms or ions.

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Tetrahedral site - An interstitial position that has a coordination number of four. An atom or ion in the tetrahedral site touches four other atoms or ions.

Covalently bonded materials frequently have complex structures in order to satisfy the directional restraints imposed by the bonding.

Diamond cubic (DC) - A special type of face-centered cubic crystal structure found in carbon, silicon, and other covalently bonded materials.

Diffraction - The constructive interference, or reinforcement, of a beam of x-rays or electrons interacting with a material. The diffracted beam provides useful information concerning the structure of the material.

Bragg's law - The relationship describing the angle at which a beam of x-rays of a particular wavelength diffracts from crystallographic planes of a given interplanar spacing (الباقي على الورقه)

In a diffractometer a moving x-ray detector records the 2y angles at which the beam is diffracted, giving a characteristic diffraction pattern

* **Factors need to be considered in order to understand crystal structures of ionically bonded solids:**

- Ionic Radii
- Electrical Neutrality
- Connection between Anion Polyhedra
- Visualization of Crystal Structures Using Computers

** **to explain Crystal Structure the following should be assumed**

- the atoms are hard spheres with Well-defined radii.
- the shortest distance between two like atoms is diameter

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Ch4

Observing Dislocations

1 Etch pits - Tiny holes created at areas where dislocations meet the surface. These are used to examine the presence and number density of dislocations.

2 Slip line - A visible line produced at the surface of a metallic material by the presence of several thousand dislocations.

3 Slip band - Collection of many slip lines, often easily visible

……..

Plastic deformation refers to irreversible deformation or change in shape that occurs when the force or stress that caused it is removed.

Elastic deformation - Deformation that is fully recovered when the stress causing it is removed.

Dislocation density - The total length of dislocation line per cubic centimeter in a material.

Critical resolved shear stress - The shear stress required to cause a dislocation to move and cause slip.

Cross-slip - A change in the slip system of a dislocation

Surface defects - Imperfections, such as grain boundaries, that form a two-dimensional plane within the crystal.

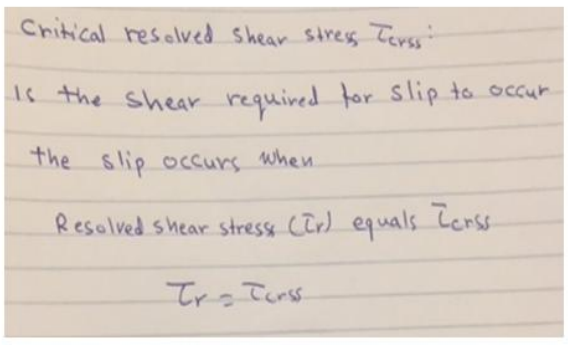
Hall-Petch equation - The relationship between yield strength and grain size in a metallic material—that is, $\sigma_y = \sigma_0 + Kd^{-1/2}$

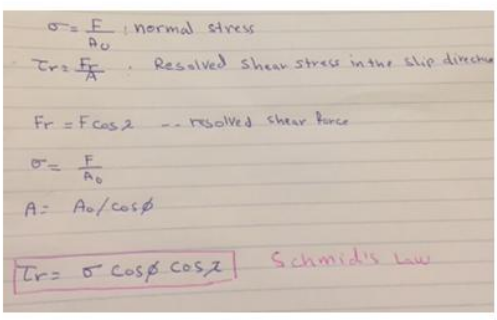
ASTM grain size number (*n*) - A measure of the size of the grains in a crystalline material obtained by counting the number of grains per square inch a magnification × 100.

Small angle grain boundary - An array of dislocations causing a small misorientation of the crystal across the surface of the imperfection.

The Burgers vector measures lattice distortion caused by a dislocation. It is found by tracing a clockwise circuit around the dislocation and transferring it to a perfect lattice, where it fails to close. The vector linking the start and end points is the Burgers vector (b = QM). For unit dislocations, it is a lattice unit vector; for partial dislocations, it is a shorter stable translation vector.

Schmid's law -The relationship between shear stress, the applied stress, and the orientation of the slip system—that is,





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***Importance of Defects**

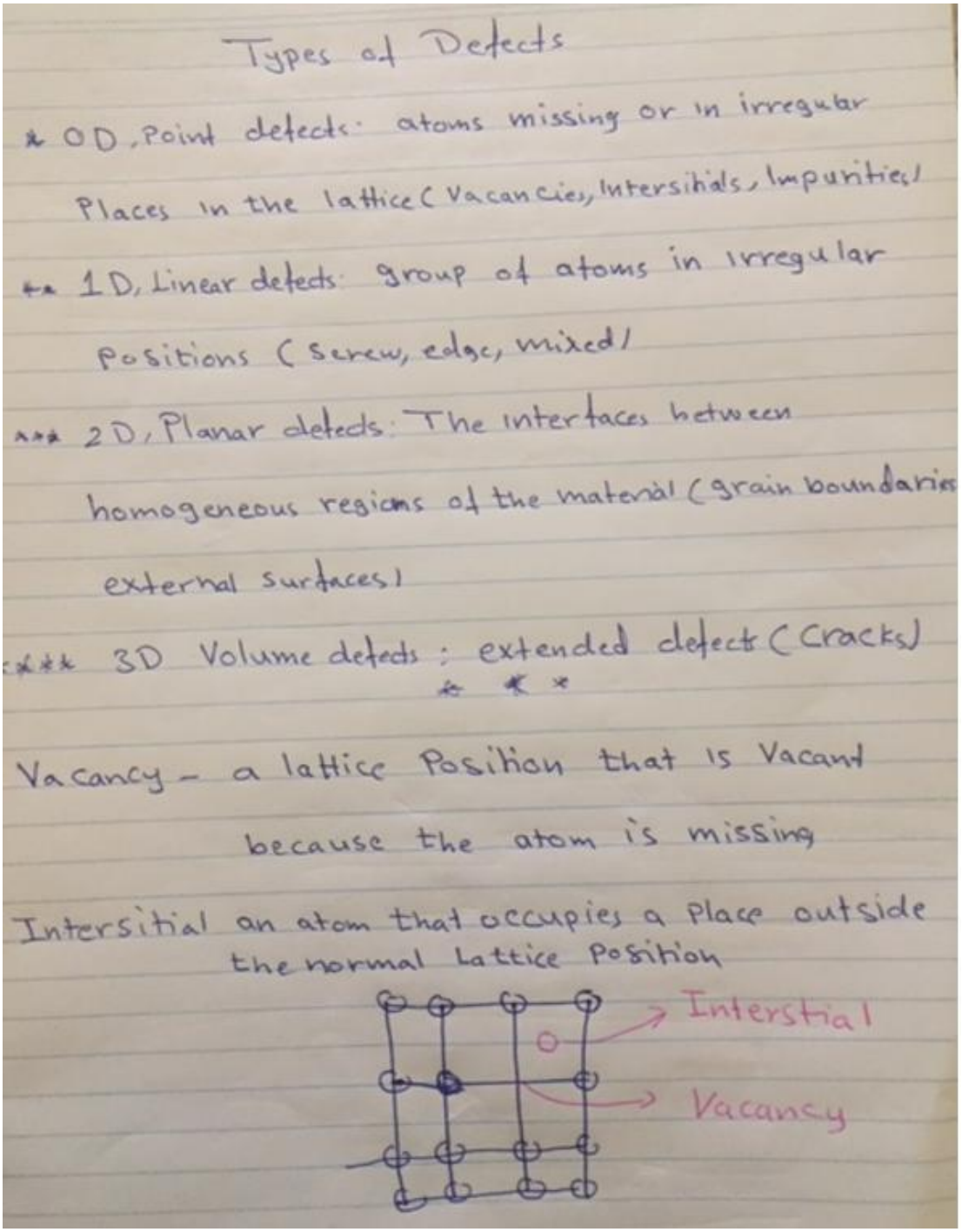
1 Effect on Mechanical Properties via Control of the Slip Process

2 Strain Hardening

3 Solid-Solution Strengthening

4 Grain-Size Strengthening

5 Effects on Electrical, Optical, and Magnetic Properties



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Ch6

Stress - Force or load per unit area of cross-section over which the force or load is acting

Strain - Elongation change in dimension per unit length.

Young's modulus - The slope of the linear part of the stress-strain curve in the elastic region, same as modulus of elasticity.

Shear modulus (G) - The slope of the linear part of the shear stress-shear strain curve.

Viscosity (η) - Measure of resistance to flow, defined as the ratio of shear stress to shear strain rate (units Poise or Pa-s).

Thixotropic behavior - Materials that show shear thinning and also an apparent viscosity that at a constant rate of shear decreases with time.

Load - The force applied to a material during testing.

Strain gage or Extensometer - A device used for measuring change in length and hence strain.

Glass temperature (Tg) - A temperature below which an otherwise ductile material behaves as if it is brittle.

Engineering stress - The applied load, or force, divided by the original cross-sectional area of the material.

Engineering strain - The amount that a material deforms per unit length in a tensile test.

Bend test - Application of a force to the center of a bar that is supported on each end to determine the resistance of the material to a static or slowly applied load.

Flexural strength or modulus of rupture -The stress required to fracture a specimen in a bend test.

Flexural modulus - The modulus of elasticity calculated from the results of a bend test, giving the slope of the stress-deflection curve.

Hardness test - Measures the resistance of a material to penetration by a sharp object.

Macrohardness - Overall bulk hardness of materials measured using loads >2 N.

Microhardness Hardness of materials typically measured using loads less than 2 N using such test as Knoop (HK).

Nano-hardness - Hardness of materials measured at 1–10 nm length scale using extremely small (~100 μN) forces.

Impact test - Measures the ability of a material to absorb the sudden application of a load without breaking.

Impact energy - The energy required to fracture a standard specimen when the load is applied suddenly.

Impact toughness - Energy absorbed by a material, usually notched, during fracture, under the conditions of impact test.

Fracture toughness - The resistance of a material to failure in the presence of a flaw.

Ductile to brittle transition temperature (DBTT) - The temperature below which a material behaves in a brittle manner in an impact test.

Notch sensitivity - Measures the effect of a notch, scratch, or other imperfection on a material's properties, such as toughness or fatigue life.

Fracture mechanics - The study of a material's ability to withstand stress in the presence of a flaw.

Fracture toughness - The resistance of a material to failure in the presence of a flaw.

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Fatigue is the lowering of strength or failure of a material due to repetitive stress which may be above or below the yield strength.

Creep - A time dependent, permanent deformation at high temperatures, occurring at constant load or constant stress.

Beach or clamshell marks - Patterns often seen on a component subjected to fatigue.

Rotating cantilever beam test - An older test for fatigue testing.

S-N curve (also known as **the Wöhler curve**) - A graph showing stress as a function of number of cycles in fatigue.

Endurance limit - An older concept that defined a stress below which a material will not fail in a fatigue test.

Fatigue life - The number of cycles permitted at a particular stress before a material fails by fatigue.

Fatigue strength - The stress required to cause failure by fatigue in a given number of cycles, such as 500 million cycles.

Notch sensitivity - Measures the effect of a notch, scratch, or other imperfection on a material's properties, such as toughness or fatigue life.

Shot peening - A process in which metal spheres are shot at a component.

Stress-rupture curve - A method of reporting the results of a series of creep tests by plotting the applied stress versus the rupture time.

Stress-corrosion - A phenomenon in which materials react with corrosive chemicals in the environment leading to the formation of cracks and lowering of strength.

Creep test - Measures the resistance of a material to deformation and failure when subjected to a static load below the yield strength at an elevated temperature.

Climb - Movement of a dislocation perpendicular to its slip plane by the diffusion of atoms to or from the dislocation line.

Creep rate - The rate at which a material deforms when a stress is applied at a high temperature.

Rupture time - The time required for a specimen to fail by creep at a particular temperature and stress.

Stress-rupture curve - A method of reporting the results of a series of creep tests by plotting the applied stress versus the rupture time.

Larson-Miller parameter - A parameter used to relate the stress, temperature, and rupture time in creep.

** **The Importance of Fracture Mechanics**

Selection of a Material

Design of a Component

Design of a Manufacturing or Testing Method

Griffith flaw - A crack or flaw in a material that concentrates and magnifies the applied stress

** **Properties Obtained from the Tensile Test**

Elastic limit /Tensile strength, Necking/Hooke's law/Poisson's ratio /Modulus of resilience (E_r) /Tensile toughness/Ductility

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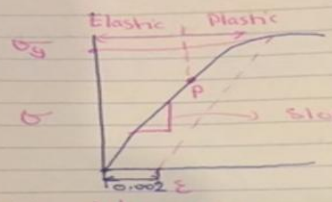
Stress-Strain behavior



* Elastic deformation
Reversible: when the stress is removed, the material returns to original shape

* Plastic deformation
Irreversible: when the stress is removed the material does not return.

Elastic deformation

In tensile tests, if the deformation is Elastic, the stress-Strain relationship is called Hooke's law

$$\sigma = E\varepsilon$$

E: is young's modulus or modulus of elasticity

Higher E ⟶ higher stiffness

Poisson's Ratio

Q: When a specimen is elongated in one direction. what happens in the other two directions?

A: The contract

The ratio of lateral to axial Strain is called Poisson's Ratio

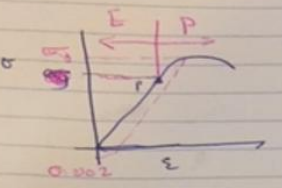
$$\nu = -\frac{\varepsilon_x}{\varepsilon_z} = -\frac{\varepsilon_y}{\varepsilon_z}$$

the - Sign ensure ν will be positive.

* ν for most metals

$\nu = 0.25$ to 0.35

Plastic deformation



σ_y: is chosen as the causing permanent strain of 0.002

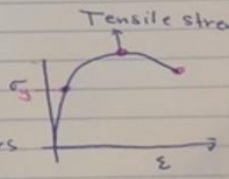
Yield point: the strain deviates from being proportional to stress

The Y. stress: is a measure of resistance to plastic deformation

* In metals plastic deformation related to dislocation and breaking of bonds with atoms

* the stress and strain are not proportional (Hooke's law is not valid)

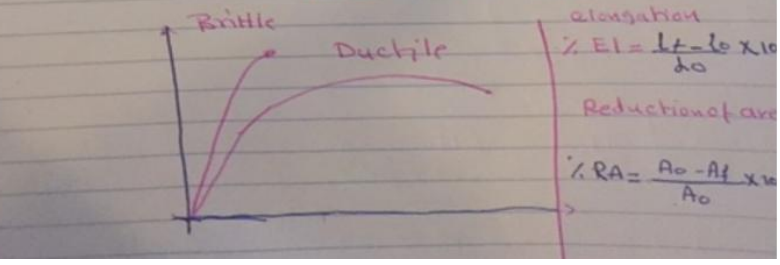
Tensile strength



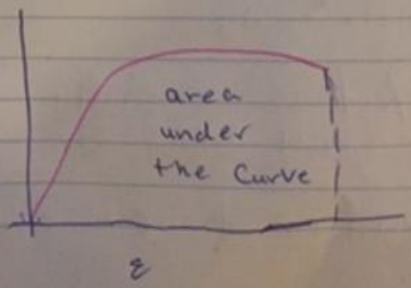
it is the stress at the max of the engineering stress Vs strain after max stress necking occurs

∴ if stress = tensile strength maintained then the specimen will Break

Tensile Prop: Ductility



Toughness: The ability to absorb energy up to fracture = the total area under stress-strain Curve



There are two modes of fracture

(I) Ductile fracture - most metals (not too cold)
- extensive plastic deformation ahead of Crack
- the crack is stable which means the it resists further extension unless applied stress is increased

(II) Brittle fracture - Ceramic, Cold metals
- little Plastic deformation
- Crack is unstable: Propagates rap
- without increase stress

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Ch7

Frank-Read source - A pinned dislocation that, under an applied stress, produces additional dislocations. This mechanism is at least partly responsible for strain hardening.

Thermoplastics - A class of polymers that consist of large, long spaghetti-like molecules that are intertwined (e.g., polyethylene, nylon, PET, etc.).

Recovery - A low-temperature annealing heat treatment designed to eliminate residual stresses introduced during deformation without reducing the strength of the cold-worked material.

Recrystallization - A medium-temperature annealing heat treatment designed to eliminate all of the effects of the strain hardening produced during cold working.

Grain growth - Movement of grain boundaries by diffusion in order to reduce the amount of grain boundary area

Warm working - A term used to indicate the processing of metallic materials in a temperature range that is between those that define cold and hot working (usually a temperature between 0.3 to 0.6 of melting temperature in K).

Heat-affected zone (HAZ) - The volume of material adjacent to a weld that is heated during the welding process above some critical temperature at which a change in the structure, such as grain growth or recrystallization, occurs.

Superplasticity - The ability of a metallic or ceramic material to deform uniformly by an exceptionally large amount.

Strain rate - The rate at which a material is deformed.

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Ch9

Phase - Any portion including the whole of a system, which is physically homogeneous within it and bounded by a surface so that it is mechanically separable from any other portions.

Gibbs phase rule - Describes the number of degrees of freedom, or the number of variables that must be fixed to specify the temperature and composition of a phase (2 + C = F + P, where pressure and temperature can change, 1 + C = F + P, where pressure or temperature is constant).

P-T diagram - A diagram describing thermodynamic stability of phases under different temperature and pressure conditions (same as a unary phase diagram).

Solubility - The amount of one material that will completely dissolve in a second material without creating a second phase.

Unlimited solubility - When the amount of one material that will dissolve in a second material without creating a second phase is unlimited.

Limited solubility - When only a maximum amount of a solute material can be dissolved in a solvent material.

Copolymer - A polymer that is formed by combining two or more different types of monomers usually with the idea of blending the properties affiliated with individual polymers, example Dylark™ a copolymer of maleic anhydride and styrene.

Hume-Rothery rules - The conditions that an alloy or ceramic system must meet if the system is to display unlimited solid solubility. Hume-Rothery's rules are necessary but are not sufficient for materials to show unlimited solid solubility.

Hume-Rothery rules:

- Size factor
- Crystal structure
- Valence
- Electronegativity

Solid-solution strengthening - Increasing the strength of a metallic material via the formation of a solid solution.

Dispersion strengthening - Strengthening, typically used in metallic materials, by the formation of ultra-fine dispersions of a second phase.

Binary phase diagram - A phase diagram for a system with two components.

Ternary phase diagram - A phase diagram for a system with three components.

Isomorphous phase diagram - A phase diagram in which components display unlimited solid solubility.

Liquidus temperature - The temperature at which the first solid begins to form during solidification.

Solidus temperature - The temperature below which all liquid has completely solidified.

Segregation - The presence of composition differences in a material, often caused by insufficient time for diffusion during solidification.

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Ch10

Dispersion strengthening - Increasing the strength of a material by forming more than one phase.

Matrix - The continuous solid phase in a complex microstructure.

Precipitate - A solid phase that forms from the original matrix phase when the solubility limit is exceeded.

Eutectic - A three-phase invariant reaction in which one liquid phase solidifies to produce two solid phases.

Intermetallic compound - A compound formed of two or more metals that has its own unique composition, structure, and properties.

Stoichiometric intermetallic compound - A phase formed by the combination of two components into a compound having a structure and properties different from either component.

Nonstoichiometric intermetallic compound - A phase formed by the combination of two components into a compound having a structure and properties different from either component.

Ordered crystal structure - Solid solutions in which the different atoms occupy specific, rather than random, sites in the crystal structure.

Peritectic - A three-phase reaction in which a solid and a liquid combine to produce a second solid on cooling.

Monotectic - A three-phase reaction in which one liquid transforms to a solid and a second liquid on cooling.

Miscibility gap - A region in a phase diagram in which two phases, with essentially the same structure, do not mix, or have no solubility in one another.

Metastable miscibility gap - A miscibility gap that extends below the liquidus or exists completely below the liquidus.

Solvus - A solubility curve that separates a single-solid phase region from a two-solid phase region in the phase diagram.

Isopleth - A line on a phase diagram that shows constant chemical composition.

Hypoeutectic alloy - An alloy composition between that of the left-hand-side end of the tie line defining the eutectic reaction and the eutectic composition.

Hypereutectic alloys - An alloy composition between that of the right-hand-side end of the tie line defining the eutectic reaction and the eutectic composition.

Ternary alloy - An alloy formed by combining three elements or components.

Ternary phase diagram - A phase diagram between three components showing the phases present and their compositions at various temperatures. This diagram requires a three-dimensional plot or is presented as two-dimensional isothermal sections of a three-dimensional diagram.

**** Strength of Eutectic Alloys**

Eutectic Colony Size /Interlamellar Spacing

Amount of Eutectic/Microstructure of the Eutectic

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Ferrous alloy

Designations - The AISI (American Iron and Steel Institute) and SAE (Society of Automotive Engineers) provide designation systems for steels that use a four- or five-digit number.

Classifications - Steels can be classified based on their composition or the way they have been processed.

Process Annealing — Eliminating Cold Work: A low-temperature heat treatment used to eliminate all or part of the effect of cold working in steels.

Annealing and Normalizing — Dispersion Strengthening: Annealing - A heat treatment used to produce a soft, coarse pearlite in steel by austenitizing, then furnace cooling. Normalizing - A simple heat treatment obtained by austenitizing and air cooling to produce a fine pearlitic structure.

Spheroidizing — Improving Machinability: Spheroidite - A microconstituent containing coarse spheroidal cementite particles in a matrix of ferrite, permitting excellent machining characteristics in high-carbon steels.

Austempering - The isothermal heat treatment by which austenite transforms to bainite.

Isothermal annealing - Heat treatment of a steel by austenitizing, cooling rapidly to a temperature between the A_1 and the nose of the TTT curve, and holding until the austenite transforms to pearlite.

Retained austenite - Austenite that is unable to transform into martensite during quenching because of the volume expansion associated with the reaction.

Tempered martensite - The microconstituent of ferrite and cementite formed when martensite is tempered.

Quench cracks - Cracks that form at the surface of a steel during quenching due to tensile residual stresses that are produced because of the volume change that accompanies the austenite-to-martensite transformation.

Marquenching - Quenching austenite to a temperature just above the M_S and holding until the temperature is equalized throughout the steel before further cooling to produce martensite.

Hardenability - Alloy steels have high hardenability.

Effect on the Phase Stability - When alloying elements are added to steel, the binary Fe-Fe_3C stability is affected and the phase diagram is altered.

Shape of the TTT Diagram - Ausforming is a thermomechanical heat treatment in which austenite is plastically deformed below the A1 temperature, then permitted to transform to bainite or martensite.

Tempering - Alloying elements reduce the rate of tempering compared with that of a plain-carbon steel.

Tool steels - A group of high-carbon steels that provide combinations of high hardness, toughness, or resistance to elevated temperatures.

Secondary hardening peak - Unusually high hardness in a steel tempered at a high temperature caused by the precipitation of alloy carbides.

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Dual-phase steels - Special steels treated to produce martensite dispersed in a ferrite matrix.

Maraging steels - A special class of alloy steels that obtain high strengths by a combination of the martensitic and age-hardening reactions.

Stainless steels - A group of ferrous alloys that contain at least 11% Cr, providing extraordinary corrosion resistance.

**** Categories of stainless steels:**

- Ferritic Stainless Steels
- Martensitic Stainless Steels
- Austenitic Stainless Steels
- Precipitation-Hardening (PH) Stainless Steels
- Duplex Stainless Steels

Cast iron - Ferrous alloys containing sufficient carbon so that the eutectic reaction occurs during solidification.

Eutectic and Eutectoid reaction in Cast Irons

**** Types of cast irons:**

- Gray cast iron
- White cast iron
- Malleable cast iron
- Ductile or nodular, cast iron
- Compacted graphite cast iron

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Nonferrous Alloys

- **Hall-Heroult process** - An electrolytic process by which aluminum is extracted from its ore.
- **Temper designation** - A shorthand notation using letters and numbers to describe the processing of an alloy. H tempers refer to cold-worked alloys; T tempers refer to age-hardening treatments.
- **Thixocasting** process in which the material is stirred during solidification, producing a partly liquid, partly solid structure that behaves as a solid when no external force is applied, yet flows as a liquid under pressure. We would select an alloy with a wide-freezing range so that a significant portion of the solidification process occurs by the growth of dendrites. A hypoeutectic aluminum-silicon alloy might be appropriate. In the thixocasting process, the dendrites are broken up by stirring during solidification. The billet is later reheated to cause melting of just the eutectic portion of the alloy, and it is then forced into the mold in its semi-solid condition at a temperature below the liquidus temperature.
- **Magnesium alloys** are used in aerospace applications, high-speed machinery, and transportation and materials handling equipment.
- Instrument grade **beryllium** is used in inertial guidance systems where the elastic deformation must be minimal; structural grades are used in aerospace applications; and nuclear applications take advantage of the transparency of beryllium to electromagnetic radiation. Beryllium is expensive, brittle, reactive, and toxic.
- **Blister copper** - An impure form of copper obtained during the copper refining process.
- **Applications for copper**-based alloys include electrical components (such as wire), pumps, valves, and plumbing parts, where these properties are used to advantage.
- **Brass** - A group of copper-based alloys, normally containing zinc as the major alloying element.
- **Bronze** - Generally, copper alloys containing tin, can contain other elements.
- **Nickel and cobalt alloys** are used for corrosion protection and for high-temperature resistance, taking advantage of their high melting points and high strengths.
- **Superalloys** - A group of nickel, iron-nickel, and cobalt-based alloys that have exceptional heat resistance, creep resistance, and corrosion resistance.

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Corrosion

Chemical corrosion - Removal of atoms from a material by virtue of the solubility or chemical reaction between the material and the surrounding liquid.

Dezincification - A special chemical corrosion process by which both zinc and copper atoms are removed from brass, but the copper is replated back onto the metal.

Graphitic corrosion - A special chemical corrosion process by which iron is leached from cast iron, leaving behind a weak, spongy mass of graphite.

Electrochemical corrosion - Corrosion produced by the development of a current in an electrochemical cell that removes ions from the material.

Electrochemical cell - A cell in which electrons and ions can flow by separate paths between two materials, producing a current which, in turn, leads to corrosion or plating.

Oxidation reaction - The anode reaction by which electrons are given up to the electrochemical cell.

Reduction reaction - The cathode reaction by which electrons are accepted from the electrochemical cell.

Electrode potential - Related to the tendency of a material to corrode. The potential is the voltage produced between the material and a standard electrode.

emf series - The arrangement of elements according to their electrode potential, or their tendency to corrode.

Nernst equation - The relationship that describes the effect of electrolyte concentration on the electrode potential in an electrochemical cell.

Faraday's equation - The relationship that describes the rate at which corrosion or plating occurs in an electrochemical cell.

polarization - Changing the voltage between the anode and cathode to reduce the rate of corrosion.

- Activation polarization is related to the energy required to cause the anode or cathode reaction

- Concentration polarization is related to changes in the composition of the electrolyte

- Resistance polarization is related to the electrical resistivity of the electrolyte.

Intergranular corrosion - Corrosion at grain boundaries because grain boundary segregation or precipitation produces local galvanic cells.

Stress corrosion - Deterioration of a material in which an applied stress accelerates the rate of corrosion.

Oxygen starvation - In the concentration cell, low-oxygen regions of the electrolyte cause the underlying material to behave as the anode and to corrode.

Crevice corrosion - A special concentration cell in which corrosion occurs in crevices because of the low concentration of oxygen.

Inhibitors - Additions to the electrolyte that preferentially migrate to the anode or cathode, cause polarization, and reduce the rate of corrosion.

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Sacrificial anode - Cathodic protection by which a more anodic material is connected electrically to the material to be protected. The anode corrodes to protect the desired material.

Passivation - Producing strong anodic polarization by causing a protective coating to form on the anode surface and to thereby interrupt the electric circuit.

Adhesive wear - Removal of material from surfaces of moving equipment by momentary local bonding, then bond fracture, at the surfaces.

Abrasive wear - Removal of material from surfaces by the cutting action of particles.

Cavitation - Erosion of a material surface by the pressures produced when a gas bubble collapses within a moving liquid.

Liquid impingement - Erosion of a material caused by the impact of liquid droplets carried by a gas stream.

+ ch1,2,heat treatment

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