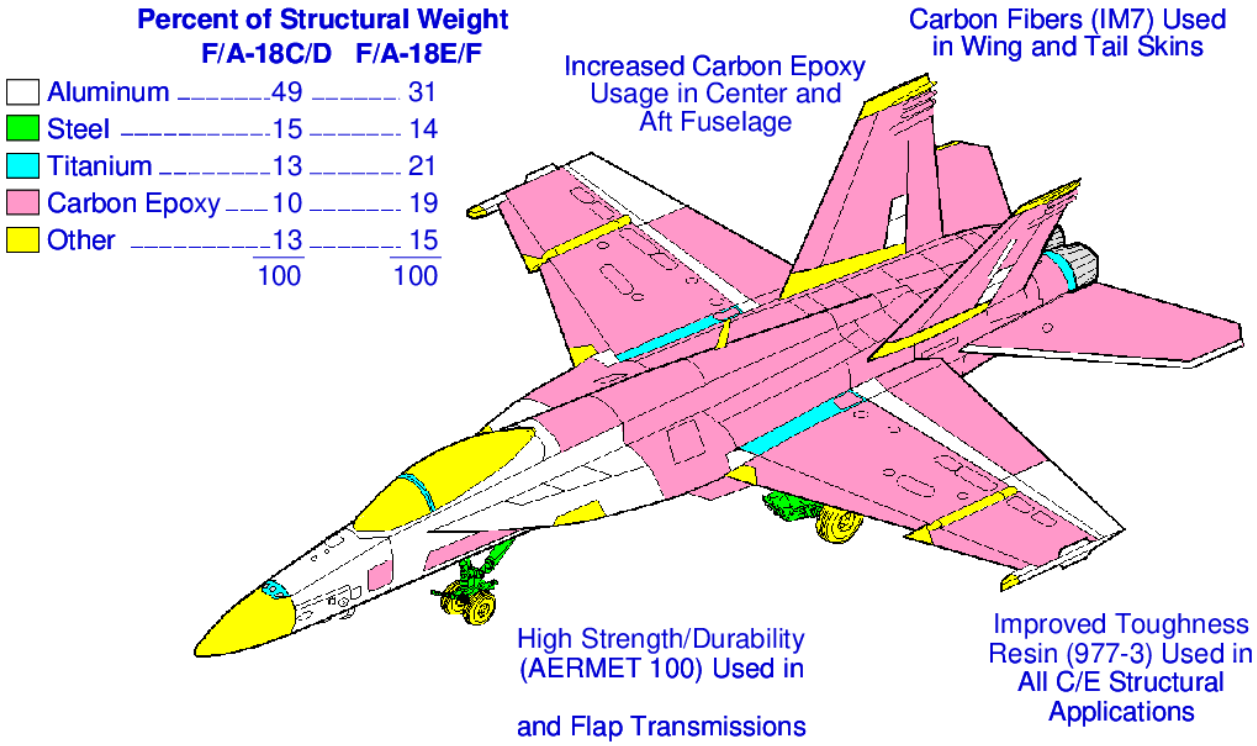
MATERIAL SCIENCE

2-Materials Applications (Week 2)

Presented by Professor Ali Hussein Ataiwi

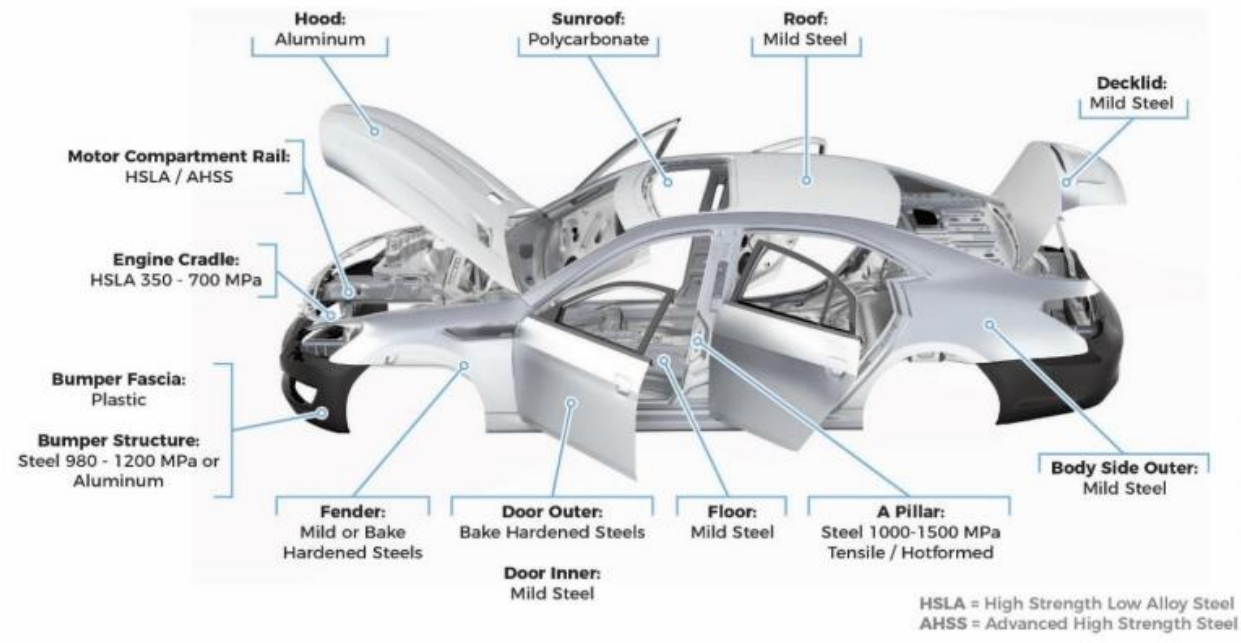
STRUCTURAL APPLICATIONS

Structural applications are applications that require mechanical performance (strength, stiffness, and vibration damping ability) in the material, which may or may not bear the load in the structure. In case the material bears the load, the mechanical property requirements are particularly exacting. An example is a building in which steel-reinforced concrete columns bear the load of the structure and unreinforced concrete architectural panels cover the face of the building. Both the columns and the panels serve structural applications and are structural materials, though only the columns bear the load. Mechanical strength and stiffness are required of the panels, but the requirements are more stringent for the columns.



Structures include buildings, bridges, piers, highways, landfill cover, aircraft, automobiles (body, bumper, drive shaft, window, engine components, and brakes), bicycles, wheelchairs, ships, submarines, machinery, satellites, missiles, tennis rackets, fishing rods, skis, pressure vessels, cargo containers, furniture, pipelines, utility poles, armored vehicles, utensils, fasteners, etc.

In addition to mechanical properties, a structural material may be required to have other properties, such as low density (lightweight) for fuel saving in the case of aircraft and automobiles, for high speed in the case of racing bicycles, and for handleability in the case of wheelchairs and armored vehicles. Another property often required is corrosion resistance, which is desirable for the durability of all structures, particularly automobiles and bridges. Yet another property that may be required is the ability to withstand high temperatures and/or thermal cycling, as heat may be encountered by the structure during operation, maintenance, or repair.



Mechanical performance is basic to the selection of a structural material. Desirable properties are high strength, high modulus (stiffness), high ductility, high toughness (energy absorbed in fracture), and high capacity for vibration damping. Strength, modulus, and ductility can be measured under tension, compression, or flexure at various loading rates as dictated by the type of loading on the structure.

Other desirable mechanical properties are fatigue resistance, creep resistance, wear resistance, and scratch resistance.

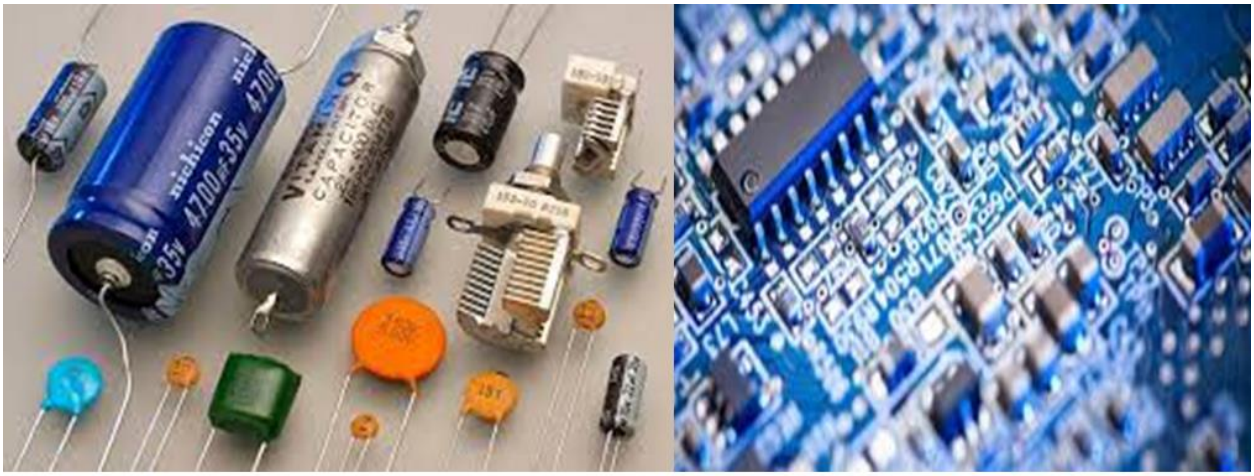
Most structures involve joints, which may be formed by welding, brazing, soldering, the use of adhesives, or by fastening. The structural integrity of joints is critical to the integrity of the overall structure.

Corrosion resistance is desirable for all structures. Metals, due to their electrical conductivity, are particularly prone to corrosion. In contrast, polymers and ceramics. because of their poor conductivity, are much less prone to corrosion.

ELECTRONIC APPLICATIONS

Electronic applications include electrical, optical, and magnetic applications, as the electrical, optical, and magnetic properties of materials are largely governed by electrons. There is overlap among these three areas of application.

Electrical applications pertain to computers, electronics, electrical circuitry (resistors, capacitors, and inductors), electronic devices (diodes and transistors), optoelectronic devices (solar cells, light sensors, and light-emitting diodes for conversion between electrical energy and optical energy), thermoelectric devices (heaters, coolers, and thermocouples for conversion between electrical energy and thermal energy), piezoelectric devices (strain sensors and actuators for conversion between electrical energy and mechanical energy), robotics, micromachines (or microelectromechanical systems, MEMS), ferroelectric computer memories.



Application of Ceramic Materials
Electronic Applications

All classes of materials are used for electronic applications. Semiconductors are at the heart of electronic and optoelectronic devices. Metals are used for electrical interconnections, EMI shielding, cables, connectors, electrical contacts, and electrical power transmission. Polymers are used for dielectrics and cable jackets. Ceramics are used for capacitors, thermoelectric devices, piezoelectric devices, dielectrics, and optical fibers.

Heat sinks are materials with high thermal conductivity that are used to dissipate heat from electronics.

Materials exhibiting both a high thermal conductivity and a low CTE are needed for heat sinks. Copper is a metal with a high thermal conductivity, but its CTE is too high. Therefore, copper is reinforced with continuous carbon fibers, molybdenum particles, or other fillers of low CTE.

THERMAL APPLICATIONS

Thermal applications are applications that involve heat transfer, whether by conduction, convection, or radiation. Heat transfer is needed in heating of buildings; in industrial processes such as casting and annealing, cooking, de-icing, etc., and in cooling of buildings, refrigeration of food and industrial materials, cooling of electronics, removal of heat generated by chemical reactions such as the hydration of cement, removal of heat generated by friction or abrasion as in a brake and as in machining, removal of heat generated by the impingement of electromagnetic radiation, removal of heat from industrial processes such as welding, etc.

Conduction refers to the heat flow from points of higher temperature to points of lower temperature in a material. It typically involves metals because of their high thermal conductivity.

Convection is attained by the movement of a hot fluid.

Radiation, i.e., blackbody radiation, is involved in space heaters. It refers to the continual emission of radiant energy from the body.

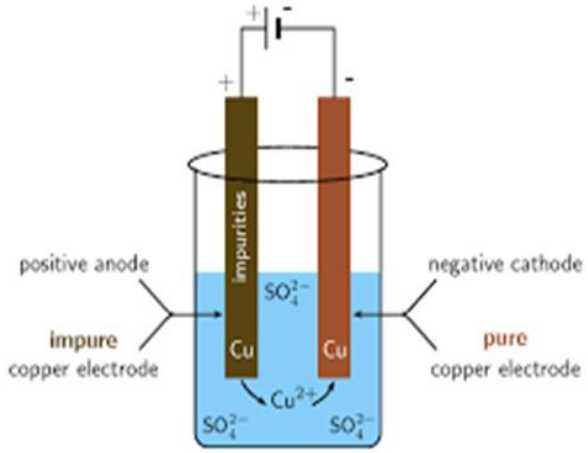
Thermal conduction can involve electrons, ions, and/or phonons. Electrons and ions move from a point of higher temperature to a point of lower temperature, thereby transporting heat. Metals conduct by electrons because they have free electrons. Diamond conducts by phonons because free electrons are not available

Diamond is the material with the highest thermal conductivity. In contrast, polymers are poor conductors because free electrons are not available and the weak secondary bonding (van der Waals' forces) between the molecules makes it difficult for the phonons to move from one molecule to another. Ceramics tend to be more conductive than polymers due to ionic and covalent bonding, making it possible for the phonons to propagate. On the other hand, ceramics tend to be poorer than metals in thermal conductivity because of the low concentration of free electrons (if any) in ceramics compared to metals.

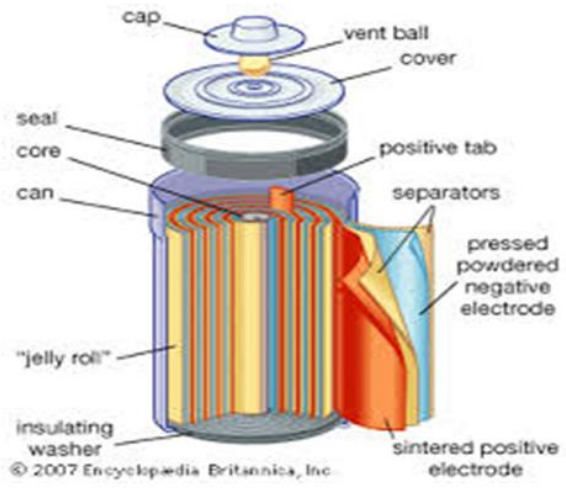
ELECTROCHEMICAL APPLICATIONS

Electrochemical applications are applications that pertain to electrochemical reactions. An electrochemical reaction involves an oxidation reaction (such as $Fe \rightarrow Fe^{2+} + 2e^-$) in which electrons are generated, and a reduction reaction (such as $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$) in which electrons are consumed. The electrode that releases electrons is the anode; the electrode that receives electrons is the cathode.

When the anode and cathode are electrically connected, electrons move from the anode to the cathode. Both the anode and cathode must be electronic conductors. As the electrons move in the wire from the anode to the cathode, ions move in an ionic conductor (called the electrolyte) placed between the anode and the cathode such that cations (positive ions) generated by the oxidation of the anode move in the electrolyte from the anode to the cathode.



Electrochemical Reaction



Electrochemical Reaction Application

Materials required for electrochemical applications include the electrodes, current collector (such as the porous carbon plates of the fuel cell mentioned above), conductive additive (such as carbon powder mixed with the MnO_2 powder in a dry cell), and electrolyte.

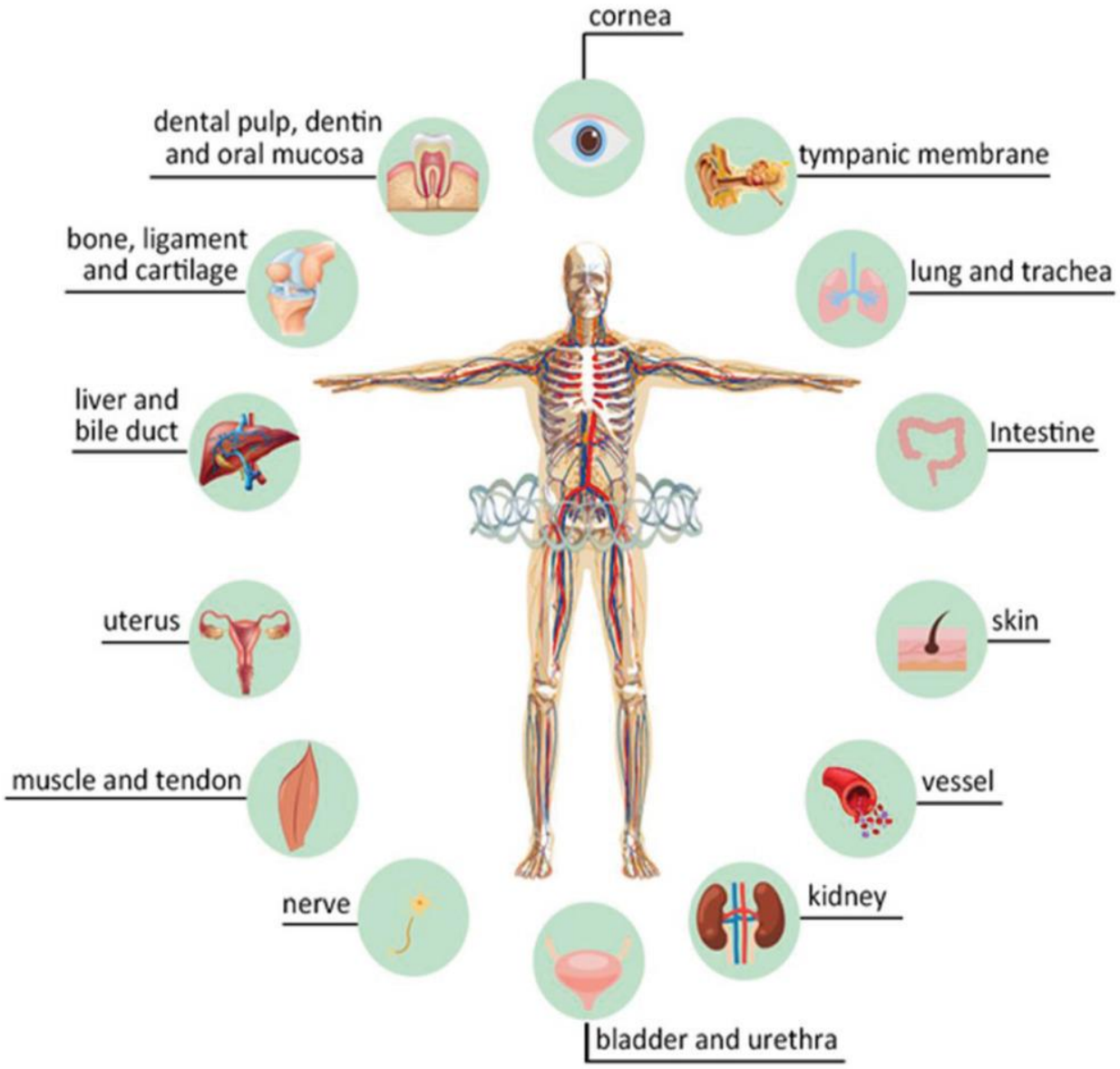
ENVIRONMENTAL APPLICATIONS

Environmental applications are applications that pertain to protecting the environment from pollution. The protection can involve the removal of a pollutant or the reduction in the amount of pollutant generated. Pollutant removal can be attained by extraction through adsorption on the surface of a solid (e.g., activated carbon) with surface porosity. It can also be attained by planting trees, which take in CO_2 gas. Pollutant generation can be reduced by changing the materials and/or processes used in industry by using biodegradable materials (materials that can be degraded by Nature so that their disposal is not necessary), by using materials that can be recycled, or by changing the energy source from fossil fuels to batteries, fuel cells, solar cells .

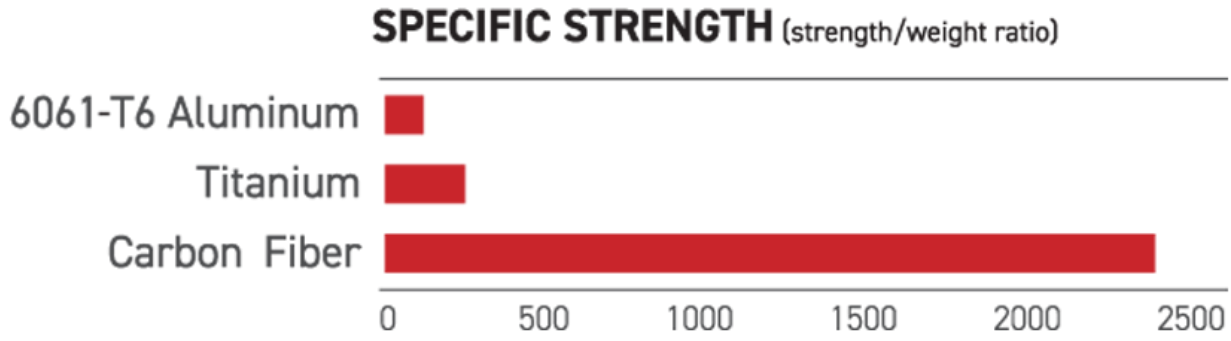
Electronic pollution is an environmental problem that has begun to be important. It arises from the electromagnetic waves (particularly radio waves) that are present in the environment due to radiation sources such as cellular telephones. Such radiation can interfere with digital electronics such as computers, thereby causing hazards and affecting society's operation. To alleviate this problem, radiation sources and electronics are shielded by materials that reflect and/or absorb radiation.

BIOMEDICAL APPLICATIONS

Biomedical applications pertain to the diagnosis and treatment of conditions, diseases, and disabilities, as well as their prevention. They include implants (hips, heart valves, skin, and teeth), surgical and diagnostic devices, pacemakers (devices for electrical control of heartbeats), electrodes for collecting or sending electrical or optical signals for diagnosis or treatment, wheelchairs, devices for helping the disabled, exercise equipment, pharmaceutical packaging (for controlled release of a drug to the body or for other purposes), and instrumentation for diagnosis and chemical analysis (such as equipment for analyzing blood and urine). Implants are particularly challenging; they need to be made of materials that are biocompatible (compatible with fluids such as blood), corrosion resistant, wear resistant, and fatigue resistant, and must be able to maintain these properties over tens of years.



Biomedical Applications



	Cheap	Strong	Light
Steel	●	●	
Aluminum	●		●
Titanium		●	●
Carbon fibre		●	●

Definitions 3 Oct 2022

Strength; the ability of a material to resist mechanical forces when in use. A material's strength in a given application depends on many factors, including its resistance to deformation and cracking, and it often depends on the shape of the member being designed

Stiffness: the resistance to a force causing a member to bend.

Carbon epoxy: The benefits of carbon fiber and its composites include:
1. Stiffness
2. High Strength
3. Electrical Conductivity
4. Fatigue Resistance
5. Good tensile strength
6. Fire Resistance/Not flammable
7. High Thermal Conductivity in some forms
8. Low coefficient of thermal expansion
9. Works well with an assortment of different materials (fiber, plastics, metals, wood, concrete)
10. Carbon fiber offers 2 to 5 times more rigidity (depending on the fiber used) than aluminum and steel.

Ductility: The ability of a material to have its shape changed (as by being drawn out into wire or thread) without losing strength or breaking.

Toughness: It is a measure of how much energy a metal can absorb before rupturing or fracturing. It also relates to the ability of the metal to bend without breaking

Fatigue resistance: It is a measure of the bearing's strength, where the loading is cyclic in direction as well as its intensity

Creep resistance: Creep is a type of metal deformation that occurs at stresses below the yield strength of a metal, generally at elevated temperatures

Wear resistance: A material's ability to resist material loss by some mechanical action.

Scratch resistance test: A quick and simple method to test coating adhesion.

EMI: Electromagnetic shielding

CTE: Coefficient of thermal Expansion: The rate at which a material expands with increase in temperature.

Annealing: It is a heat treatment process that changes the physical and sometimes also the chemical properties of a material to increase ductility and reduce the hardness to make it more workable.

Phonon: It is a collective excitation in a periodic, elastic arrangement of atoms or molecules in condensed matter,

Adsorption: It is the adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid to a surface.