MAE 438/538 Smart Materials

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Grading scheme for MAE 438

- Test 1 25%
- Test 2 25%
- Final 50%

Grading scheme for MAE 538

- Test 1 20%
- Test 2 20%
- Final 40%
- Paper 20%

Test dates

- Test 1: Feb. 3, 2005
- Test 2: Mar. 22, 2005

Smart materials

Materials for smart structures

Smart structures

Structures that can sense stimuli and respond to them in appropriate fashions

Civil structures

- Buildings
- Bridges
- Piers
- Highways
- Airport runways
- Landfill cover

Lightweight structures

- Aircraft
- Satellites
- Turbine blades
- Automobiles
- Bicycles
- Sporting goods
- Wheelchairs
- Transportable bridges

Functions for structures

- Structural
- Vibration reduction
- Self-sensing of strain/stress
- Self-sensing of damage
- Electromagnetic interference (EMI) shielding
- Lightning protection
- Self-heating (e.g., deicing)
- Self-healing

Applications of strain-stress sensing

- Traffic monitoring
- Weighing (including weighing in motion)
- Building facility management
- Security
- Structural vibration control

Applications of damage sensing

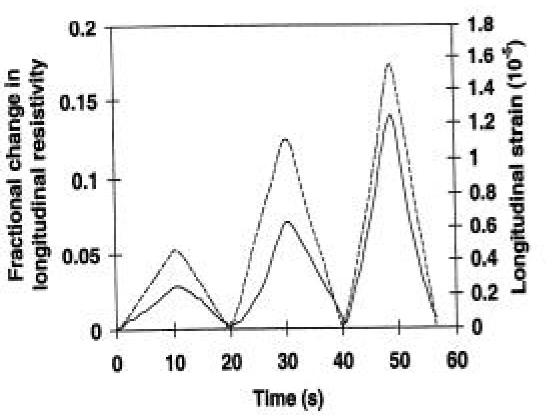
- Structural health monitoring
- Damage/ microstructural evolution study

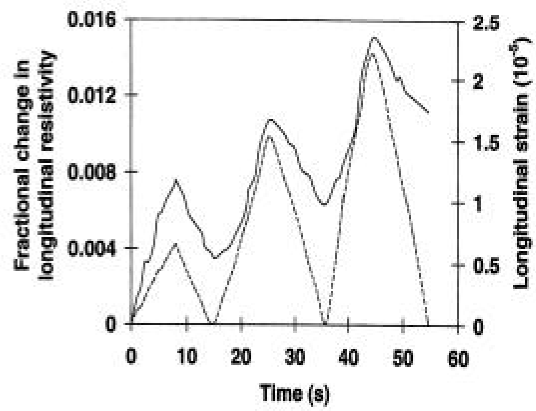
Damage sensing methods

- Acoutic emission
- Electrical resistivity measurement
- Optical fiber sensor embedment

Piezoresistivity

- Change of electrical resistivity due to strain
- Gage factor = fractional change in resistance per unit strain
  (more than 2)
- Gage factor up to 700 attained in carbon fiber reinforced cement





Self-healing concept

- Embedding microcapsules of monomer in composite
- Having catalyst in composite outside the microcapsules
- Upon fracture of microcapsule, monomer meets catalyst, thereby former a polymer which fills the crack.

Problems with self-healing

- Toxicity of monomer
- High cost of catalyst

Types of smartness

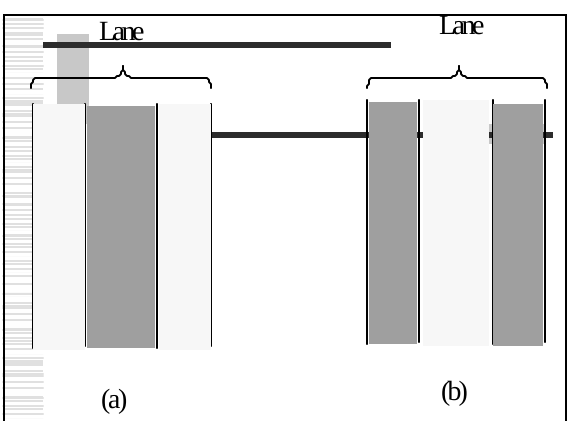
- Extrinsic smartness
- Intrinsic smartness

Advantages of intrinsic smartness

- Low cost
- High durability
- Large functional volume
- Absence of mechanical property loss

Advantages of automatic highway

- Safety
- Mobility



Applications of materials

Topic 1

Reading assignment

- Chung, "Composite Materials", Ch. 1 on Applications.
- Askeland and Phule, The Science and Engineering of Materials, 4th Edition, Ch. 15 on Polymers.

Applications

- Structural applications
- Electronic applications
- Thermal applications
- Electrochemical applications
- Environmental applications
- Biomedical applications

History of human civilization

- Stone Age
- Bronze Age
- Iron Age
- Steel Age
- Space Age
- Electronic Age

Types of materials

- Metals
- Ceramics
- Polymers
- Semiconductors
- Composite materials

Ceramics

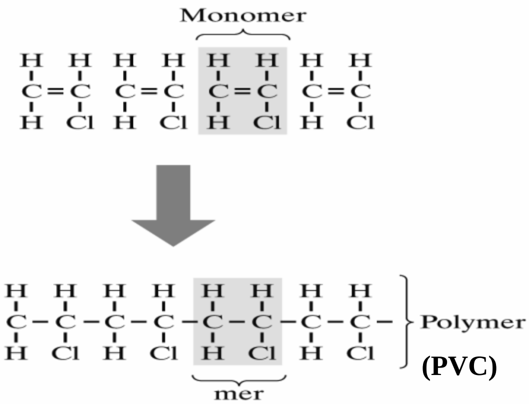
- Ionic/covalent bonding
- Very hard (brittle)
- High melting temperature
- Low electrical/thermal conductivity

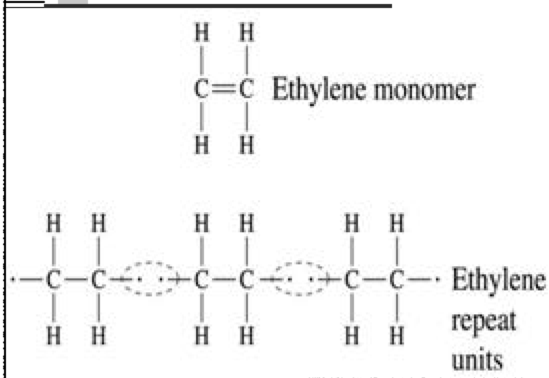
Examples of ceramics

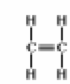
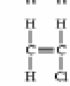
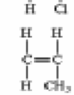
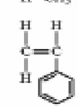
- Al_2O_3 (aluminum oxide or alumina)
- Fe_3O_4 (iron oxide or ferrite)
- WC (tungsten carbide)
- Cement (silicates)

Polymers

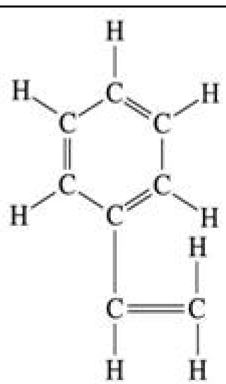
- Molecules
- Soft
- Low melting temperature
- Low electrical/thermal conductivity

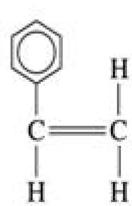




Name	Monomer
General-use polymers	
Polyethylene	
Polyvinyl chloride	
Polypropylene	
Polystyrene[b]	

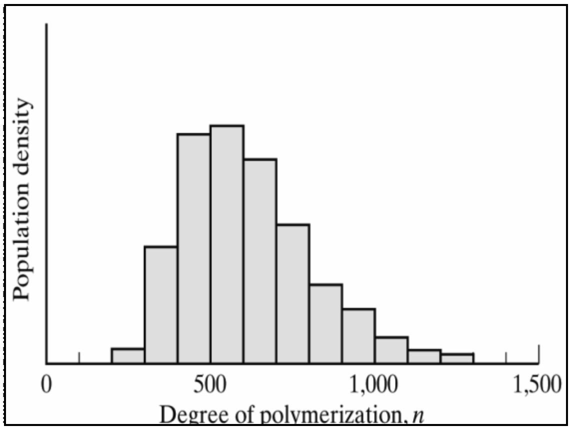
Styrene



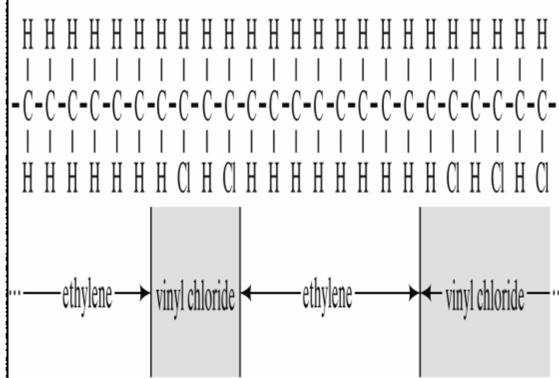


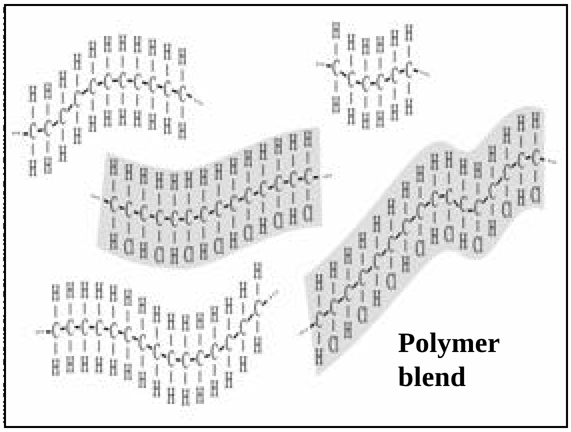
Examples of polymers

- Rubber
- Polyester
- Nylon
- Cellulose
- Pitch

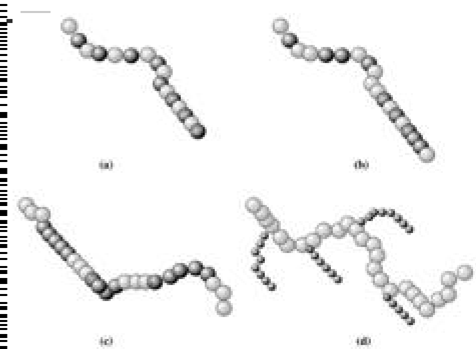


Copolymer

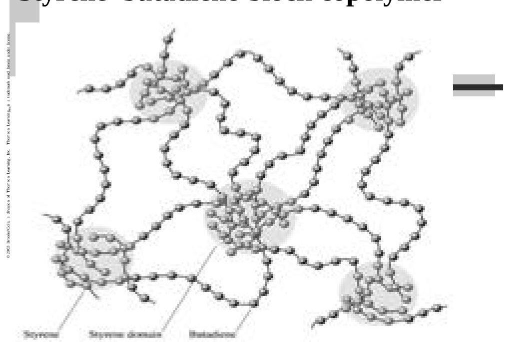


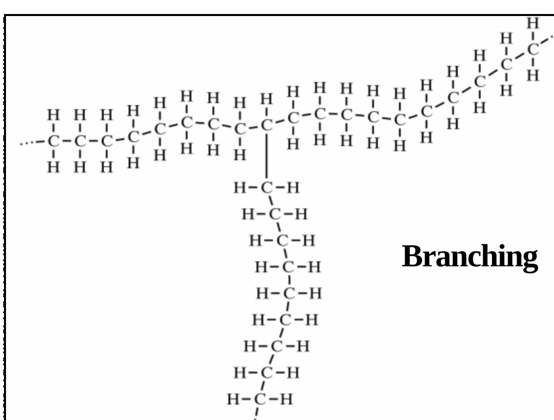


Polymer blend

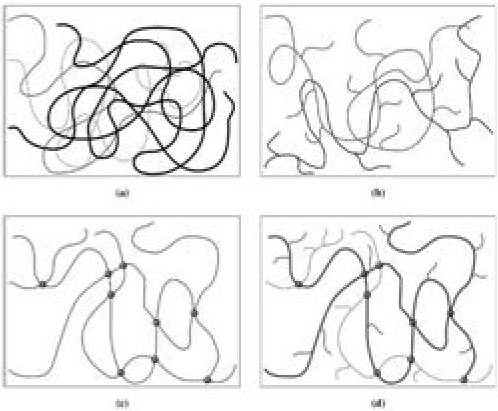


Styrene-butadiene block copolymer





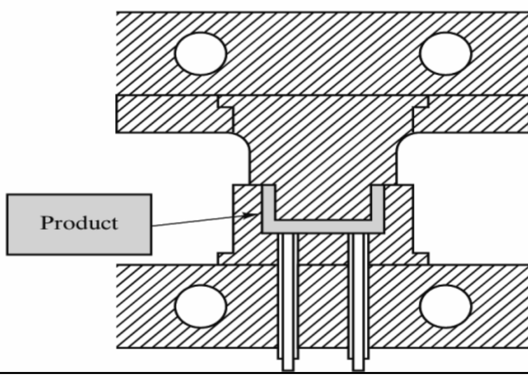
Branching



Types of polymer

- Thermoplastic (softens upon heating)
- Thermoset (does not soften upon heating)

Compression molding

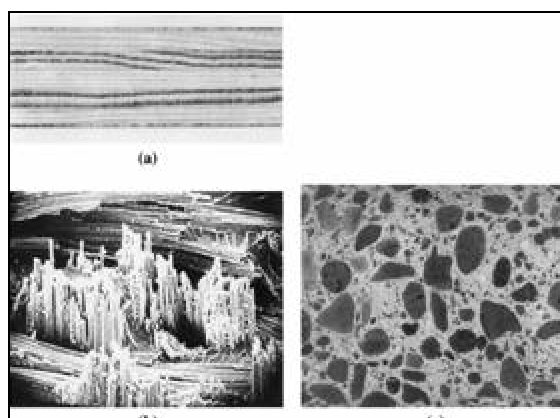


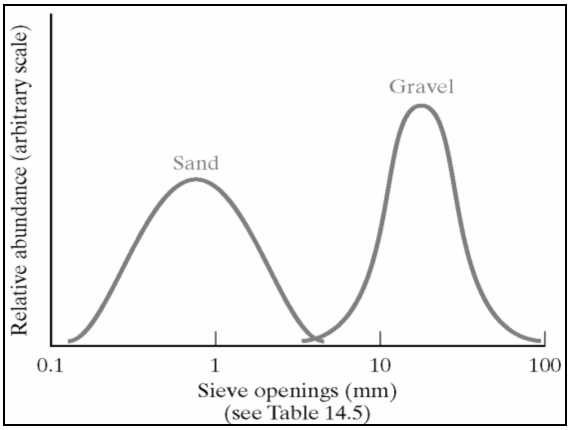
Composites

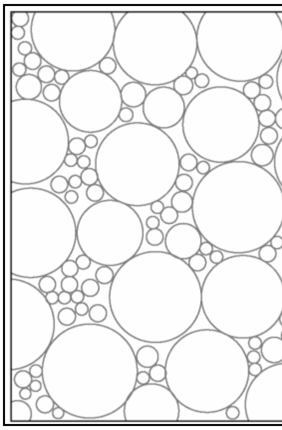
Artificial combinations of materials

Composite materials

- Polymer-matrix composites
- Cement-matrix composites
- Metal-matrix composites
- Carbon-matrix composites
- Ceramic-matrix composites







Composite materials

- Particulate
- Fibrous (discontinuous fibers)
- Fibrous (continuous fibers)
- Lamellar

Cement-matrix composites

- Cement paste
- Mortar
- Concrete

Carbons

- Graphite
- Diamond
- Fullerenes (buckminsterfullerenes)
- Carbon nanotubes
- Turbostratic carbon
- Diamond-like carbon (DLC)
- Intercalation compounds of graphite
- Exfoliated graphite (“worms”)
- Flexible graphite

Structures

- Buildings, bridges, piers, highways, landfill cover
- Aircraft, satellites, missiles
- Automobiles (body, bumper, shaft, window, engine components, brake, etc.)
- Bicycles, wheelchairs
- Ships, submarines
- Machinery
- Tennis rackets, fishing rods, skis

Structures (continued)

- Pressure vessels, cargo containers
- Furniture
- Pipelines, utility poles
- Armor, helmets
- Utensils
- Fasteners
- Repair materials

Multifunctionality in structures

- Load bearing
- Assembly and packaging
- Vibration reduction (damping)
- Structural health monitoring (damage sensing)
- Structural vibration control
- Modulus control

Multifunctionality in structures (continued)

- Self-sensing of strain, damage and temperature
- Building management
- Building security
- Thermal insulation
- Self-heating (e.g., deicing)
- Self-healing
- Electromagnetic interference (EMI) shielding
- Low observability (Stealth)
- Energy generation

Embedded or attached devices or materials

- Sensors (e.g., , strain gages, optical fibers)
- Actuators (e.g., electrostrictive materials, magnetostrictive materials, shape-memory alloys, etc.)
- Viscoelastic materials
- Magnetorheological materials
- Electrorheological materials

Disadvantages of embedded or attached devices

- High cost
- Poor durability
- Poor repairability
- Limited functional volume
- Degradation of mechanical properties

Structural performance

- High strength
- High modulus (stiffness)
- Mechanical fatigue resistance
- Thermal fatigue resistance
- Low density
- Corrosion resistance
- Moisture resistance
- Freeze-thaw durability

Structural performance (continued)

- High temperature resistance
- Thermal shock resistance
- Low thermal expansion coefficient
- Creep resistance
- Low fluid permeability
- Repairability
- Maintainability
- Processability

Electronic applications

- Electrical applications
- Optical applications
- Magnetic applications

Electrical applications

- Computers
- Electronics
- Electrical circuitry (resistors, capacitors, inductors)
- Electronic devices (diodes, transistors)
- Optoelectronic devices (solar cells, light sensors, light-emitting diodes)
- Thermoelectric devices (heaters, coolers, thermocouples)

Electrical applications (continued)

- Piezoelectric devices (sensors, actuators)
- Robotics
- Micromachines (microelectromechanical systems or MEMS)
- Ferroelectric computer memories
- Electrical interconnections (solder joints, thick-film conductors, thin-film conductors)
- Dielectrics (electrical insulators in bulk, thick-film and thin-film forms)

Electrical applications (continued)

- Substrates for thin films and thick films
- Heat sinks
- Electromagnetic interference (EMI) shielding
- Cables
- Connectors
- Power supplies
- Electrical energy storage
- Motors
- Electrical contacts, brushes (sliding contacts)

Electrical applications (continued)

- Electrical power transmission
- Eddy current inspection (use of a magnetically induced electrical current to indicate flaws in a material)

Optical applications

- Lasers
- Light sources
- Optical fibers (materials of low optical absorptivity for communication and sensing)
- Absorbers, reflectors and transmittors of electromagnetic radiation
- Photography
- Photocopying
- Optical data storage
- Holography

Magnetic applications

- Transformers
- Magnetic recording (data storage)
- Magnetic computer memories
- Magnetic field sensors
- Magnetic shielding
- Magnetically levitated trains

Magnetic applications (continued)

- Robotics
- Micromachines
- Magnetic particle inspection
- Magnetic energy storage
- Magnetostriction
- Magnetorheological fluids
- Magnetic resonance imaging (MRI, for patient diagnosis)
- Mass spectrometry (for chemical analysis)

Electronic packaging

- Electrical interconnections
- Chip carriers
- Interlayer dielectrics
- Encapsulations
- Heat sinks
- Thermal interface materials
- Housings
- EMI shielding

Thermal applications

- Heating and cooling of buildings
- Industrial heating (casting, annealing, deicing, etc.)
- Refrigeration
- Microelectronic cooling
- Heat removal (brakes, cutting, welding, chemical reactions, etc.)

Mechanisms of heat transfer

- Conduction (by electrons, ions or phonons)
- Convection (by hot fluid, whether forced or natural convection)
- Radiation (black-body radiation, particularly infrared radiation, for space heaters)

Materials for thermal applications

- Thermal conductors
- Thermal insulators
- Heat retention materials (high heat capacity)
- Thermal interface materials
- Thermoelectric materials

Electrochemical reaction

- Anode
- Cathode
- Electrolyte
- Catalyst (optional)

Electrochemical applications

- Batteries
- Fuel cells (galvanic cells in which the reactants are continuously supplied, e.g., the hydrogen-oxygen fuel cell)

Environmental protection

- Pollutant removal (e.g., filtration, absorption by activated carbon)
- Reduction in the amount of pollutant generated (e.g., use of biodegradable polymers)
- Recycling
- Electronic pollution control

Biomedical applications

- Diagnosis
- Treatment
- Scope: conditions, diseases, disabilities, and their prevention

Biomedical materials and devices

- Implants
- Bone replacement materials
- Bone growth support
- Surgical and diagnostic devices
- Pacemaker
- Electrodes for collecting or sending electrical or optical signals

Biomedical materials and devices (continued)

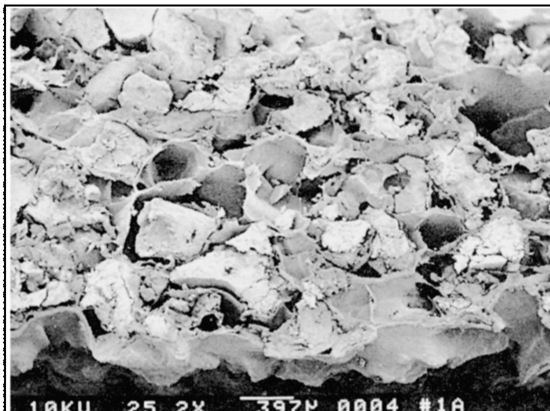
- Wheelchairs
- Devices for helping the disabled
- Exercise equipment
- Pharmaceutical packaging
- Instrumentation

Requirements of implant materials

- Biocompatible
- Corrosion resistant
- Wear resistant
- Fatigue resistant
- Durability for tens of years

A biomedical composite material

- Particulate composite
- Ceramic particles: hydroxyapatite + tricalcium phosphate
- Polymer matrix: collagen



Desirable qualities of an adsorption material

- Large adsorption capacity
- Pores accessible from the outside
- Pore size large enough for relatively large molecules or ions to lodge
- Ability to be regenerated or cleaned after use
- Fluid dynamics for fast movement of the fluid
- Selective adsorption of certain species

Pore size nomenclature

- Macropores (exceeds 500 Å)
- Mesopores (between 20 and 500 Å)
- Micropores (between 8 and 20 Å)
- Micromicropores (less than 8 Å)

Functions of filter materials

- Molecule or ion removal (by adsorption)
- Particle removal