POLYMER NANOCOMPOSITES

Master in Nanoscience
Low dimensional systems and nanostructures
January 24th 2008

Lourdes del Valle Carrandí
POLYMER NANOCOMPOSITES

- INTRODUCTION
- WHY NANOCOMPOSITES?
- POLYMER MATRICES
- NANOFILLERS
- PROCESSING
- PROPERTIES
- APPLICATIONS
- CONCLUSIONS
INTRODUCTION

Polymer nanocomposites:
- Combination of a polymer matrix and inclusions that have at least one dimension (i.e. length, width, or thickness) in the nanometer size range.

NANOPARTICLES → 3-D
NANOSHEETS → 2-D
NANOWIRES → 1-D
WHY NANOCOMPOSITES?

Traditional composites: the length scale of the fillers is in micrometers.

Polymer coils are 40 nm in diameter, some nanofillers are on the same order of magnitude.

Molecular interaction between polymer and nanofillers will give polymer nanocomposites unusual properties that conventional polymers do not possess.
POLYMER MATRICES

Thermoplastic resins: long chains that when heated they soften.
Examples: PS, PVC, PP, PC, PPO, PMMA, PE, PA, PAN...

Thermoset resins: crosslinked chains forming a resin with a 3-D structure which doesn’t melt.
Examples: phenolic, epoxy, aminos...

Elastomers: elastic or rubberlike.
Examples: PI, natural and synthetic rubber, SBR...
NANOFILLERS

- Montmorillonite organoclays (MMT).
- Carbon nanofibers (CNFs).
- Carbon nanotubes (CNTs)
- Metallic nanoparticles.
- Others.
Montmorillonite organoclays (MMT)

Tetrahedral silicate layer: $\text{SiO}_4$ groups linked together to form a hexagonal network.

Octaedral alumina layer: two sheets of closely packed oxygens or hydroxyls, between which octahedrally coordinated aluminium atoms are equidistant from six oxygens or hydroxyls.

Two tetrahedral layers sandwich the octahedral one, sharing their apex oxygens with the latter.

- **Stiffness, strength, flame resistance**
- **Gas permeability, sweling in solvents**

**PROBLEM!** They are hydrophilic materials: must be made hydrophobic to become compatible with most of the polymers (hydrophobic).
Carbon nanofibers (CNFs)

Form of vapour-grown carbon fiber which is a discontinous graphitic filament produced in the gas phase from the pyrolysis of hydrocarbons. The resulting nanofibers typically have an outer diameter of 60 to 200 nm, a hollow core of 30-90 nm, and a length on the order of 50 to 100 microns. The use of vapor-grown carbon nanofibers has been proposed for providing improved mechanical, electronic and thermal transport properties to polymers.
Carbon nanotubes (CNTs)

Nanotubes have high Young’s modulus and tensile strength, and can be metallic, semiconducting, or semimetallic, depending on the helicity.

Carbon nanotubes are excellent candidates for stiff and robust structures.

There has been intense interest in nanocomposites of polymers and carbon nanotubes (CNT) because of the large change of the properties (conductivity, elasticity, viscosity, thermal conductivity) exhibited for relative low CNT concentrations (=1 % volume fraction).
Metallic nanoparticles

Materials based on nano-sized metals will surely represent an adequate solution to many present and future technological demands, since they exhibit novel properties (plasmon resonance, superparamagnetism, etc.). Metals undergo the most considerable property change by size reduction, and their composites with polymers are very interesting for functional applications because the properties of nano-sized metals (optical, magnetic, dielectric, and thermal transport properties) leave unmodified after embedding in polymers.
There are other nanofillers such as exfoliated graphite and silicon carbide (SiC) that have been used to form polymer nanocomposites with enhanced properties (mechanical, thermal and electrical).

Boron nitride (BN) is an excellent thermal conductor and electrical insulator, polymers filled with boron nitride should be specially good materials for dissipating heat.
POLYMER-CLAY NANOCOMPOSITES
Layered silicates can be easily separated and dispersed (weak forces that stack the layers together) in an adequate solvent in which the polymer is soluble. The polymer absorbs onto the delaminated sheets, and when the solvent is evaporated, the sheets sandwich the polymer to form an ordered, multilayered structure.
Melt processing

Layered silicate is mixed with the polymer in the molten state. If layers’ surfaces are compatible enough with the selected polymer, it can be inserted into the interlayer space and form the final nanocomposite. In this case, no solvent is required.
In-situ polymerization

Now, we have monomers (instead of polymer).
We add the clays and we include the initiator.
The polymerization takes places.
The generated polymer chains, as they grow, will separate the clays and enter in the interlayer space.
The polymer-clay nanocomposite is obtained.
Emulsion polymerization

In this case the monomer (hydrophobic) escapes from the water and enters into the micelles (drops formed by molecules of emulsifier).

Polymerization: inside the micelles.

- High molecular weights
- High reaction rates
- Good control of the temperature of the reactor
PROPERTIES

DEPEND ON: MATRIX, NANOFILLERS, etc.

**Improved properties**
- Mechanical properties (tensile strength, stiffness, toughness).
- Gas barrier.
- Synergistic flame retardant additive.
- Dimensional stability.
- Thermal expansion.
- Thermal conductivity.
- Ablation resistance.
- Chemical resistance.
- Reinforcement.

**Disadvantages**
- Viscosity increase (limits processability).
- Dispersion and distribution difficulties.
- Sedimentation.
- Black colour when different carbon containing nanoparticles are used.
APPLICATIONS

DEPEND ON: MATRIX, NANOFILLERS, etc.

- Automobile (gasoline tanks, bumpers, interior and exterior panels, etc.).
- Construction (shaped extrusions, panels).
- Electronics and electrical (printed circuits, electric components).
- Food packaging (containers, films).
- Cosmetics (controlled release of “active ingredients”).
- Dentistry (filling materials).
- Environment (biodegradable materials).
- Gas barrier (tennis balls, food and beverage packaging).
- Flame retardant.
- Military, aerospace, and commercial applications.
CONCLUSIONS

- Polymer nanocomposites will soon generate smart membranes, new catalysts and sensors, new generation of photovoltaic and fuel cells, smart microelectronic, micro-optical and photonic components and systems, or intelligent therapeutic vectors that combine targeting, imaging, therapy and controlled release properties.

- The real potential of these materials will remain untapped, however, until the nanoscale mechanisms responsible for macroscopic properties are unveiled and are further exploited to make radically new materials.