COMPOSITE MATERIALS

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ISSUES TO ADDRESS

- Polymers
  - Applications
  - Classification
  - Fabrication
Applications of Polymers

- Packaging (Film, Containers)
- Coatings
- Structural
- Adhesives
- Clothing
- Household Goods
- Electronics
- Sporting Goods
- Biomedical
POLYMERS

Range of Polymers

Polymers

- Fibres
- Film
- Rope
- Paints
- Textiles
- Monofilaments
- Membranes
- Photoresists
- Sealants
- Adhesives
- Additives
- Fillers
- Absorbents
- Extrudates
- Mouldings
- Containers
- Foams
POLYMERS
Polymers are very large molecules made when hundreds of monomers join together to form long chains.

The word ‘polymer’ comes from the Greek words poly (meaning ‘many’) and meros (meaning ‘parts’).

Plastics are synthetic polymers that can be shaped by heat or pressure.
The term polymer comes from “poly”, meaning many, and “mer”, meaning units. Hence, polymers are composed of many units—in this case, structural units called monomers.

A *monomer* is any unit that can be converted into a polymer. Similarly, a *dimer* is a combination of two monomers, a *trimer* is a combination of three monomers, and so on.

Polymer chains are formed from the reaction of many monomers to form long chain hydrocarbons, sometimes called macromolecules, but more commonly referred to as polymers.

Polymers are mostly based in carbon, oxygen, and hydrogen. Some have Si, F, Cl, S
What is a polymer?

**Poly**  
**mer**  
many repeat unit

Polyethylene (PE)  
Polyvinyl chloride (PVC)  
Polypropylene (PP)

Adapted from Fig. 14.2, *Callister 7e.*
When all the repeating units along a chain are of the same type, the resulting polymer is called a **homopolymer**.

There is no restriction in polymer synthesis that prevents the formation of compounds other than homopolymers; and, in fact, chains may be composed of two or more different mer units, in what are termed **copolymers**.

Adapted from Fig. 14.2, *Callister 7e.*
The molecules in polymers are gigantic in comparison to the hydrocarbon molecules heretofore discussed; because of their size they are often referred to as macromolecules. Within each molecule, the atoms are bound together by covalent interatomic bonds. For most polymers, these molecules are in the form of long and flexible chains, the backbone of which is a string of carbon atoms; many times each carbon atom singly bonds to two adjacent carbons atoms on either side, represented schematically in two dimensions as follows:

\[
-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-\overset{\text{C}}{\text{C}}-
\]
Polymerization is the reaction used to convert monomers into polymers. The monomers in a polymer are joined together by covalent bonds between atoms.

In a covalent bond, each atom shares one or more electrons with another atom. The bonds are sometimes shown as lines.
What are polymers made from?

- Many polymers are formed from **alkenes**, which are a family of hydrocarbon molecules with the general formula $C_nH_{2n}$.

- Alkenes contain at least one double covalent bond between carbon atoms. The double bond makes them very reactive.

  - The simplest alkene is **ethene** ($C_2H_4$).
  
  - The second simplest alkene is **propene** ($C_3H_6$).
Since most polymers are organic in origin, we briefly review some of the basic concepts relating to the structure of their molecules. First, many organic materials are hydrocarbons; that is, they are composed of hydrogen and carbon.

Furthermore, the intramolecular bonds are covalent. Each carbon atom has four electrons that may participate in covalent bonding, whereas every hydrogen atom has only one bonding electron. A single covalent bond exists when each of the two bonding atoms contributes one electron, as represented schematically in Figure for a molecule of methane (CH₄). Double and triple bonds between two carbon atoms involve the sharing of two and three pairs of electrons, respectively. For example, in ethylene, which has the chemical formula C₂H₄, the two carbon atoms are doubly bonded together, and each is also singly bonded to two hydrogen atoms, as represented by the structural formula.
HYDROCARBON MOLECULES

• where − and = denote single and double covalent bonds, respectively.
• An example of a triple bond is found in acetylene, C₂H₂:

[H−C≡C−H]

• Molecules that have double and triple covalent bonds are termed unsaturated. That is, each carbon atom is not bonded to the maximum (or four) other atoms; as such, it is possible for another atom or group of atoms to become attached to the original molecule. Furthermore, for a saturated hydrocarbon, all bonds are single ones (and saturated), and no new atoms may be joined without the removal of others that are already bonded. Some of the simple hydrocarbons belong to the paraffin family; the chainlike paraffin molecules include methane (CH₄), ethane (C₂H₆), propane (C₃H₈), and butane (C₄H₁₀). Compositions and molecular structures for paraffin molecules. The covalent bonds in each molecule are strong, but only weak hydrogen and van der Waals bonds exist between molecules, and thus these hydrocarbons have relatively low melting and boiling points. However, boiling temperatures rise with increasing molecular weight.
### Compositions and Molecular Structures for Some of the Paraffin Compounds: \( \text{C}_n\text{H}_{2n+2} \)

<table>
<thead>
<tr>
<th>Name</th>
<th>Composition</th>
<th>Structure</th>
<th>Boiling Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>( \text{CH}_4 )</td>
<td>( \text{H} – \text{C} – \text{H} )</td>
<td>-164</td>
</tr>
<tr>
<td>Ethane</td>
<td>( \text{C}_2\text{H}_6 )</td>
<td>( \text{H} – 2\text{C} – \text{H} )</td>
<td>-88.6</td>
</tr>
<tr>
<td>Propane</td>
<td>( \text{C}_3\text{H}_8 )</td>
<td>( \text{H} – 3\text{C} – \text{H} )</td>
<td>-42.1</td>
</tr>
<tr>
<td>Butane</td>
<td>( \text{C}<em>4\text{H}</em>{10} )</td>
<td>( \text{H} – 4\text{C} )</td>
<td>-0.5</td>
</tr>
<tr>
<td>Pentane</td>
<td>( \text{C}<em>5\text{H}</em>{12} )</td>
<td>( \text{H} – 5\text{C} )</td>
<td>36.1</td>
</tr>
<tr>
<td>Hexane</td>
<td>( \text{C}<em>6\text{H}</em>{14} )</td>
<td>( \text{H} – 6\text{C} )</td>
<td>69.0</td>
</tr>
</tbody>
</table>
HYDROCARBON MOLECULES

- Hydrocarbon compounds with the same composition may have different atomic arrangements, a phenomenon termed isomerism.
- For example, there are two isomers for butane; normal butane has the structure:

  \[
  \begin{array}{c}
  \text{H} \\
  \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\
  \text{H} - \text{H} - \text{H} - \text{H}
  \end{array}
  \]

- whereas a molecule of isobutane is represented as follows:

  \[
  \begin{array}{c}
  \text{H} \\
  \text{H} - \text{C} - \text{H} \\
  \text{H} - \text{H} - \text{H} - \text{H}
  \end{array}
  \]

\[
\begin{array}{c}
\text{H} \\
\text{H} - \text{C} - \text{C} - \text{C} - \text{H} \\
\text{H} - \text{H} - \text{H} - \text{H}
\end{array}
\]
### Some Common Hydrocarbon Groups

<table>
<thead>
<tr>
<th>Family</th>
<th>Characteristic Unit</th>
<th>Representative Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohols</td>
<td>R—OH</td>
<td>Methyl alcohol</td>
</tr>
<tr>
<td>Ethers</td>
<td>R—O—R’</td>
<td>Dimethyl ether</td>
</tr>
<tr>
<td>Acids</td>
<td>R—CO</td>
<td>Acetic acid</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>R—CO</td>
<td>Formaldehyde</td>
</tr>
<tr>
<td>Aromatic hydrocarbons</td>
<td></td>
<td>Phenol</td>
</tr>
</tbody>
</table>

*The simplified structure denotes a phenyl group.*
It is useful to classify polymers in order to make generalizations regarding physical properties, formability, and reactivity.

The appropriate classification scheme can change, however, because there are several different ways in which to classify polymers.

The first scheme groups polymers according to their chain chemistry. Carbonchain polymers have a backbone composed entirely of carbon atoms. In contrast, heterochain polymers have other elements in the backbone, such as oxygen in a polyether, –C–O–C–.

We can also classify polymers according to their macroscopic structure—that is, independent of the chemistry of the chain or functional groups. There are three categories of polymers according to this scheme: linear, branched, and networked (crosslinked) polymers.
Polymers
(a) natural and (b) synthetic

Naturally occurring polymers—those derived from plants and animals—have been used for many centuries; these materials include wood, rubber, hair, nails, skin, cotton, wool, leather, and silk.

Other natural polymers such as proteins, enzymes, starches, and cellulose are important in biological and physiological processes in plants and animals.
Modern scientific research tools have made possible the determination of the molecular structures of this group of materials, and the development of numerous polymers, which are synthesized from small organic molecules.

Many of our useful plastics, rubbers, and fiber materials are synthetic polymers. In fact, since the conclusion of World War II, the field of materials has been virtually revolutionized by the advent of synthetic polymers.

The synthetics can be produced inexpensively, and their properties may be managed to the degree that many are superior to their natural counterparts. In some applications metal and wood parts have been replaced by plastics, which have satisfactory properties and may be produced at a lower cost.
Classifying Polymers by Synthesis

**Addition Polymers**

These polymers are made from monomers that link together without losing any atoms. These monomers typically have at least one carbon-carbon double bond. Polyethylene is an addition polymer.

**Condensation Polymer**

These polymers are made from monomers that link together and lose small molecules such as water (H₂O), ammonia (NH₃), or hydrogen chloride (HCl). These monomers have 2 or more reactive functional groups. Most condensation polymers are copolymers.
Polymer Classification

Addition Polymers

Many

\[
\begin{align*}
\text{Ethylene monomer} & \\
\text{Polyethylene polymer} \quad \rightarrow \\
\text{etc. - C - C - C - C - C - etc.} & \quad \text{or} \\
\end{align*}
\]

Condensation Polymer

\[
\begin{align*}
\text{Terephthalic acid} & \\
\text{Ethylene glycol} & \\
\text{Dacron} \quad \rightarrow \\
\end{align*}
\]
## Addition Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Structure</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Addition polymers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene</td>
<td>$(\text{CH}_2\text{CH}_2)_n$</td>
<td>Films, packaging, bottles</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>$\left[\begin{array}{c} \text{CH}_2\text{CH} \ \text{CH}_3 \end{array}\right]_n$</td>
<td>Kitchenware, fibers, appliances</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>$\left[\begin{array}{c} \text{CH}_2\text{CH} \ \text{CH} \end{array}\right]_n$</td>
<td>Packaging, disposable food containers, insulation</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td>$\left[\begin{array}{c} \text{CH}_2\text{CH} \ \text{Cl} \end{array}\right]_n$</td>
<td>Pipe fittings, clear film for meat packaging</td>
</tr>
</tbody>
</table>
### Condensation Polymer

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Structure</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condensation polymers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyurethane</td>
<td>$\left[ \begin{array}{c} C-\text{NH-R-\text{NH-C-O-R'-O}} \ O \end{array} \right]_n$</td>
<td>&quot;Foam&quot; furniture stuffing, spray-on insulation, automotive parts, footwear, water-protective coatings</td>
</tr>
<tr>
<td></td>
<td>$R, R' = -\text{CH}_2-\text{CH}_2-$ (for example)</td>
<td></td>
</tr>
<tr>
<td>Polyethylene terephthalate</td>
<td>$\left[ \begin{array}{c} O-\text{CH}_2-\text{CH}_2-\text{O-C-} \ C-O \end{array} \right]_n$</td>
<td>Tire cord, magnetic tape, apparel, soft-drink bottles</td>
</tr>
<tr>
<td>(a polyester)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nylon 6,6</td>
<td>$\left[ \begin{array}{c} \text{NH-(CH}_2\text{)}_6-\text{NH-C-(CH}_2\text{)}_4- \ \text{O-} \end{array} \right]_n$</td>
<td>Home furnishings, apparel, carpet fibers, fishing line, polymer blends</td>
</tr>
</tbody>
</table>

Classification of polymers according to macroscopic structure:

Molecular Structures for Polymers

- Linear
- Branched
- Cross-Linked
- Network

Adapted from Fig. 4.7, *Callister & Rethwisch 3e.*
Linear Polymers

- polymers in which the mer units are connected end-to-end along the whole length of the chain
- These types of polymers are often quite flexible
  - Van der waal’s forces and H-bonding are the two main types of interactions between chains
  - Some examples – polyethylene, teflon, PVC, polypropylene

![Diagram of linear polymers](image)
Branched Polymers

Polymer chains can branch:

- Or the fibers may aligned parallel, as in fibers and some plastic sheets.
- Chains off the main chain (backbone)
- This leads to inability of chains to pack very closely together
- These polymers often have lower densities
- These branches are usually a result of side-reactions during the polymerization of the main chain
- Most linear polymers can also be made in branched forms
Branched Polymers

• Polymer chains can branch:

- Propylene monomer
- Polypropylene polymer
• Or the fibers may aligned parallel, as in fibers and some plastic sheets.
• chains off the main chain (backbone)
  – This leads to inability of chains to pack very closely together
    » These polymers often have lower densities
• These branches are usually a result of side-reactions during the polymerization of the main chain
  – Most linear polymers can also be made in branched forms
Crosslinked polymers

Molecular structure

- adjacent chains attached via covalent bonds
  - Carried out during polymerization or by a non-reversible reaction after synthesis (referred to as crosslinking)
  - Materials often behave very differently from linear polymers
  - Many “rubbery” polymers are crosslinked to modify their mechanical properties; in that case it is often called vulcanization
  - Generally, amorphous polymers are weak and cross-linking adds strength: vulcanized rubber is polyisoprene with sulphur cross-links:
Crosslinked polymers

Cross-Linking Polymers
Kevlar is a cross-linked polymer.

Polymer chains of Kevlar crystallize in parallel, like dry spaghetti noodles in a box. These parallel chains are cross-linked with hydrogen bonds.

As a result, Kevlar is 5 times stronger than steel.
Kevlar is 5 times stronger than steel. It is used in bulletproof vests, helmets, suspension bridge cables, and radial tires.
Network Polymers

- Polymers that are “trifunctional” instead of bifunctional
- There are three points on the mer that can react
- This leads to three-dimensional connectivity of the polymer backbone
  - Highly crosslinked polymers can also be classified as network polymers
  - Examples: epoxies, phenol-formaldehyde polymers
Finally, polymers can be classified according to their formability.

- Thermoplastics
- Thermosets
- Elastomers

Thermoplastic

Thermoset

Cross-linking atoms or atom groups
Polymers that can be repeatedly shaped and reshaped are called *thermoplastics*, whereas those polymers that cannot be reshaped at any temperature once they are set are termed *thermosets*.

**Thermoplastics** - reversible in phase by heating and cooling. Solid phase at room temperature and liquid phase at elevated temperature.

**Thermosets** - irreversible in phase by heating and cooling. Change to liquid phase when heated, then follow with an irreversible exothermic chemical reaction. Remain in solid phase subsequently.

Often times network polymers are thermosets, and linear and branched polymers are thermoplastics. Hence, the thermoplastic/thermoset distinction is worthy of some elaboration.

**Elastomers** – Rubbers. Material that is elastic in some way. If a moderate amount of deforming force is added, the elastomer will return to its original shape. Useful for fibers.
Polymer Classification

Thermoplastics

Thermosettings

Thermoplastics: 90% Plastics
Thermosettings: 10% Plastics
Thermoset and thermoplastic materials are found in the insulation and jacketing of many cables on the market today. **Thermoplastic materials** consist of chains of molecules which separate when heat is applied. This molecular construction gives thermoplastics the ability to melt and remold time and time again. On the other hand, **thermoset materials** consist of polymer structures which are cured or vulcanized to become natural or synthetic rubber materials. Irradiation, heat, or chemical reactions can be used to cure the material. During the curing process, polymer chains are cross-linked with other molecules which is why thermoset materials are also known as **cross-linked materials**.
Thermoplastic resins and thermosetting resins, both types become soft when heated, but they differ in their behavior after they cool to a solid.

While thermoplastic resins become soft again when heated once more, thermosetting resins do not change their form any more even if they are heated again. The reason why a plastic cup placed inadvertently near the fire becomes deformed is that it is made of a thermoplastic resin.

Handles of frying pans and knobs of pot lids are made of thermosetting resins. Because these resins have good electrical characteristics, they were used for switches and sockets of electric lamps. However, because of their poor productivity, they have been replaced gradually by thermoplastic resins. Today, thermoplastic resins make up nearly 90% of these electrical components. Thermoplastic resins are further divided into "general-purpose plastics" and high-performance "engineering plastics". Thermoplastic resins are divided into crystalline and noncrystalline resins.
Thermoplastics

- Acetals
- Acrylics - PMMA
- Acrylonitrile-Butadiene-Styrene - ABS
- Cellulosics
- Fluoropolymers - PTFE, Teflon
- Polyamides (PA) - Nylons, Kevlar
- Polysters - PET
- Polyethylene (PE) - HDPE, LDPE
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)
# Thermoplastics

<table>
<thead>
<tr>
<th>Material</th>
<th>Uses</th>
<th>Notes</th>
<th>Material</th>
<th>Uses</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic (PMMA)</td>
<td><img src="image1.png" alt="Image" /> Stiff, hard and uniform strength. Scratches easily. Clear; has good optical properties. Non-toxic. Good insulator, easily machined and polishes well</td>
<td></td>
<td>Acrylonitrile butadiene-styrene (ABS)</td>
<td><img src="image2.png" alt="Image" /> High impact strength. Tough and scratch resistant. Resistant to chemicals</td>
<td></td>
</tr>
<tr>
<td>Rigid polystyrene (HDPS)</td>
<td><img src="image3.png" alt="Image" /> Light, hard, stiff, often transparent. Brittle with low impact strength. Water resistant. The toughened type can be coloured</td>
<td></td>
<td>Polyvinyl chloride (PVC)</td>
<td><img src="image4.png" alt="Image" /> Chemical and weather resistant. Needs a stabiliser for outdoor use. Good electrical insulator</td>
<td></td>
</tr>
<tr>
<td>Expanded polystyrene (LDPS)</td>
<td><img src="image5.png" alt="Image" /> Buoyant, lightweight. A good sound and heat insulator</td>
<td></td>
<td>Polyethylene terephthalate (PET)</td>
<td><img src="image6.png" alt="Image" /> Used extensively for mineral water bottles. Clear and very tough</td>
<td></td>
</tr>
<tr>
<td>Polyamide (nylon)</td>
<td><img src="image7.png" alt="Image" /> Usually creamy in colour. Hard, tough and resistant to wear. Low friction. Machines well, but very difficult to join</td>
<td></td>
<td>Polyethylene (polythene, PE)</td>
<td><img src="image8.png" alt="Image" /> Tough, very popular. Quite cheap. Available in a wide range of colours. Fairly low melting point</td>
<td></td>
</tr>
</tbody>
</table>
Thermoplastics
Thermosets

- Amino resins
- Epoxies
- Phenolics
- Polyesters
- Polyurethanes
- Silicones
## Thermo-sets

<table>
<thead>
<tr>
<th>Material</th>
<th>Uses</th>
<th>Notes</th>
<th>Material</th>
<th>Uses</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester resin (GRP)</td>
<td></td>
<td>Stiff, hard and brittle. Used for casting and, when reinforced by</td>
<td>Epoxy resin</td>
<td></td>
<td>Very strong, especially when reinforced by glass or carbon fibres.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>glass fibres, produces GRP. Easy to colour. Excellent for outdoor</td>
<td></td>
<td></td>
<td>Used as an adhesive for unlike materials e.g. metals to plastics</td>
</tr>
<tr>
<td>Urea formaldehyde (UF)</td>
<td>Stiff, hard and</td>
<td>Excellent electrical insulator. Used as an adhesive</td>
<td>Melamine</td>
<td></td>
<td>Stiff, hard and strong. Scratch resistant. Low water absorption.</td>
</tr>
<tr>
<td></td>
<td>brittle. Excellent</td>
<td></td>
<td>formaldehyde</td>
<td></td>
<td>Stain resistant. No odour. Available in a wide range of colours</td>
</tr>
<tr>
<td></td>
<td>electrical insulator</td>
<td></td>
<td>(MF)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Elastomers

- Natural rubber
- Synthetic rubbers
  - butadiene rubber
  - butyl rubber
  - chloroprene rubber
  - ethylene-propylene rubber
  - isoprene rubber
  - nitrile rubber
  - polyurethanes
  - silicones
  - styrene-butadiene rubber
  - thermoplastic elastomers
## Polymer Matrix Composites

### Examples of fiber-reinforced materials and applications

<table>
<thead>
<tr>
<th>Material</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borsic aluminum</td>
<td>Fan blades in engines, other aircraft and aerospace applications</td>
</tr>
<tr>
<td>Kevlar™-epoxy and Kevlar™-polyester</td>
<td>Aircraft, aerospace applications (including space shuttle), boat hulls, sporting goods (including tennis rackets, golf club shafts, fishing rods), flak jackets</td>
</tr>
<tr>
<td>Graphite-polymer</td>
<td>Aerospace and automotive applications, sporting goods</td>
</tr>
<tr>
<td>Glass-polymer</td>
<td>Lightweight automotive applications, water and marine applications, corrosion-resistant applications, sporting goods equipment, aircraft and aerospace components</td>
</tr>
</tbody>
</table>
## Properties and Processing Characteristics of Key Thermoplastic Resins

<table>
<thead>
<tr>
<th>Properties</th>
<th>PEEK</th>
<th>PPS</th>
<th>Nylon</th>
<th>PEI</th>
<th>PP</th>
<th>PMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service temperature</td>
<td>250°C</td>
<td>220°C</td>
<td>70°C</td>
<td>170°C</td>
<td>55°C</td>
<td>65°C</td>
</tr>
<tr>
<td></td>
<td>(480°F)</td>
<td>(430°F)</td>
<td>(160°F)</td>
<td>(340°F)</td>
<td>(130°F)</td>
<td>(150°F)</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>1.32</td>
<td>1.35</td>
<td>1.15</td>
<td>1.27</td>
<td>0.91</td>
<td>1.19</td>
</tr>
<tr>
<td>Processing temperature</td>
<td>385°C</td>
<td>330°C</td>
<td>275°C</td>
<td>315°C</td>
<td>175°C</td>
<td>205°C</td>
</tr>
<tr>
<td></td>
<td>(725°F)</td>
<td>(625°F)</td>
<td>(525°F)</td>
<td>(600°F)</td>
<td>(350°F)</td>
<td>(400°F)</td>
</tr>
<tr>
<td>Moisture absorption</td>
<td>Very low</td>
<td>Very low</td>
<td>High</td>
<td>Average</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Bonding characteristics</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
</tr>
</tbody>
</table>
## Potential for commercial resins-property/process characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Thermoset</th>
<th>Thermoplastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Service temperature</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Toughness</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Processing temperature</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Recyclability</td>
<td>Limited</td>
<td>Good</td>
</tr>
</tbody>
</table>

# Polymer Matrix Composites

## General Properties of Thermoset and Thermoplastic Composites

<table>
<thead>
<tr>
<th>Property</th>
<th>Thermoset Composites</th>
<th>Thermoplastic Composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber volume</td>
<td>Medium to high</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Fiber length</td>
<td>Continuous and discontinuous</td>
<td>Continuous and discontinuous</td>
</tr>
<tr>
<td>Molding time</td>
<td>Slow: 0.5 to 4 h</td>
<td>Fast: less than 5 min</td>
</tr>
<tr>
<td>Molding pressure</td>
<td>Low: 1 to 7 bars</td>
<td>High: greater than 14 bars</td>
</tr>
<tr>
<td>Material cost</td>
<td>Low to high</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Safety/handling</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Solvent resistance</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Heat resistance</td>
<td>Low to high</td>
<td>Low to medium</td>
</tr>
<tr>
<td>Storage life</td>
<td>Good (6 to 24 months with refrigeration)</td>
<td>Indefinite</td>
</tr>
</tbody>
</table>
Thanks for your kind attention

THE END
Any Questions