MM 604: Polymer and Composite Technology

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The course comprises of assignments, three tests and end sem exam.

Course Content

Unit 1: Polymers: Classification of Polymers, Co-Polymers, Thermoset and Thermoplastics, Crystalline and Amorphous Polymers, Polymerization, Degree of Polymerization, Glass transition temperature, Molecular weight of polymer and its determination by various techniques,

Unit 2: Physical methods of polymer analysis such as IR, DSC, TGA, XRD etc, Viscoelasticity, Polymer blends and alloys: thermodynamics, morphology and properties.

Unit 3: Composites: Conventional polymer composites, Fiber reinforced composites, Nanofillers and their composites,

Unit 4: Composite manufacturing techniques: Solution-cast, Melt-mixing, Extrusion, Compression molding, Resin transfer, Resin infusion, Vacuum casting and electrospinning.

Unit 5: Defence Applications: Coatings (Superhydrophobic, Self Healing), Fire retardant, Corrosion Resistant, EMI Shielding, Environmental responsive polymers (Self healing, Phase change and Shape Memory), Polymer composites in aerospace applications. Service life prediction methodologies of polymers and composites

Text Book(s):

•*V.R. Gowariker, Polymer Science, Wiley Eastern, 1995*

•*F. N. Billmeyer, Textbook of Polymer Science, Wiley Interscience, 1971.*

• *Materials Science & Engg: An Introduction, William D. Callister*

Reference Book(s):

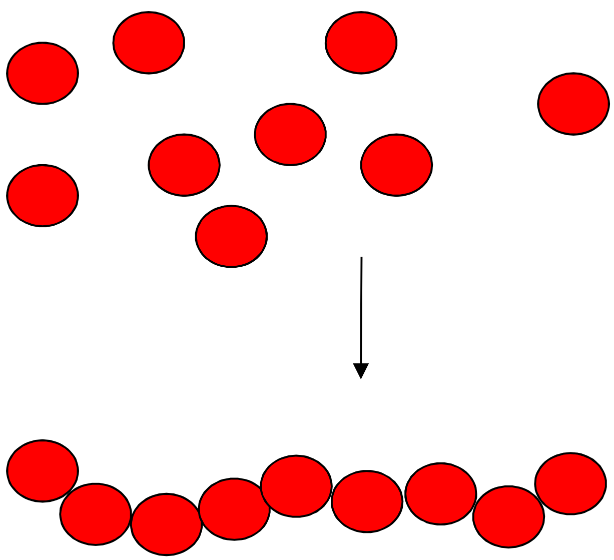
•*Kumar and S. K. Gupta, Fundamentals and Polymer Science and Engineering, Tata McGraw-Hill, 1978*

•*Epel, J.N.:Engineering Plastics, Engineering Materials Handbook, ASM International 1988.*

•*Brydson, A.J. : Plastics Materials, Princeton, N.J., 1966.*

•*Composite Materials Science & Enginering, KK Chawla*

What is a Polymer?



- A long molecule made up from lots of small molecules called
- *monomers.*
- In Greek, *'Poly'* means many and *'meros'* means parts
- Polymers generally refers to long chain molecules also know as macromolecules

A + A + A + A → -A-A-A-A-

A + B + A + B → -A-B-A-B-

Polymers: Introduction

- Easy processability and shaping
- Polymers or prepolymers are raw materials for plastics after physical compounding they become plastics
- Polymers may be utilized as fibers, elastomers, thickners, ion exchange resins, paints and adhesives
- Typical examples are:

  Thermoplastic (PE, PP, ABS, PET, PVC, PS, PVA, PPO, PU, PVDF, PMMA, PEO, polyamides etc.), Thermosets (epoxy, phenolic resins, PU foam, bakelite etc.), polysiloxane, nucleic acids, proteins, DNA etc.…………to name a few.

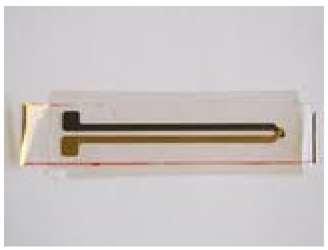
Applications

- Some of the application of polymers are buckets, bottles, ropes, electric appliances, toys, CDs, computers, cars, aircrafts, space scuttles etc.

Expanded Polystyrene cup

Polyurethane foam matress

Thermoplastic PU based shoes



Poly(vinylidene fluoride)
based sensor

PP based car bumper

Poly(acrylo-butadiene styrene)
Copolymer based car dashboard

Poly(methyl methacrylate)
contact lens

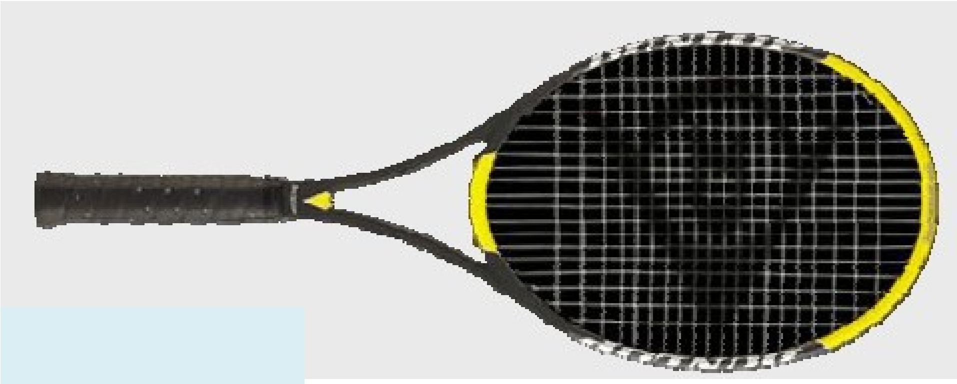
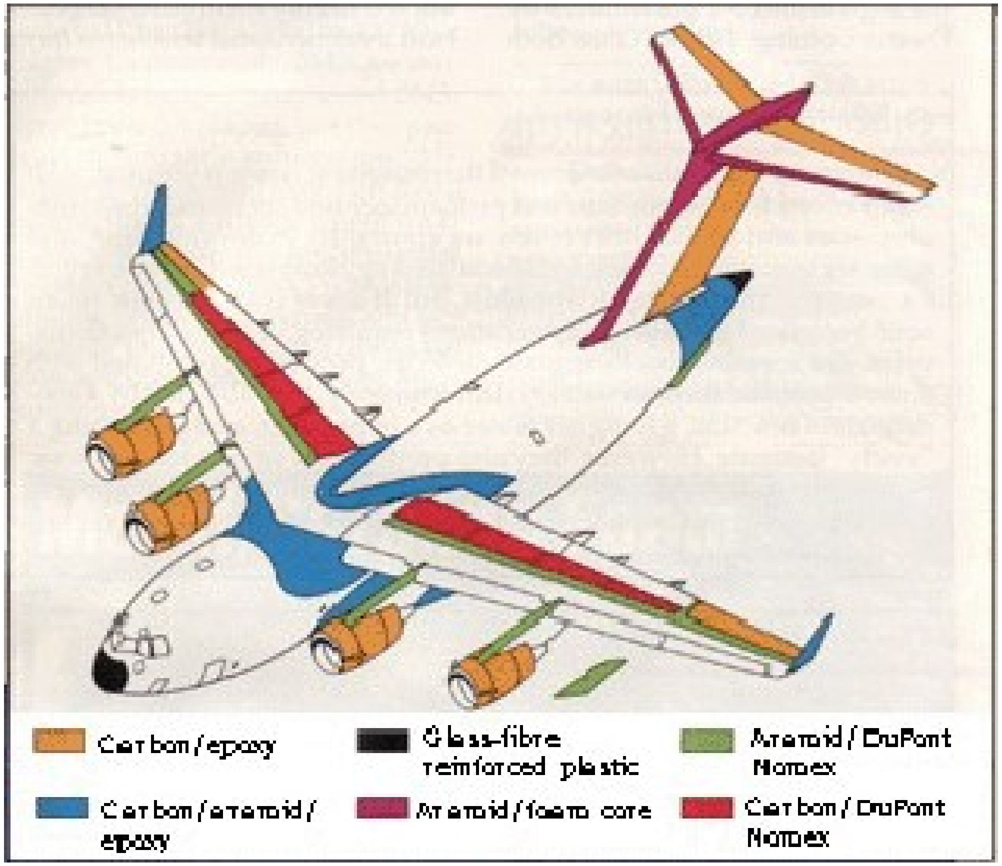
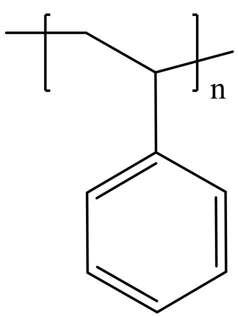


Fig. 2: New windmill

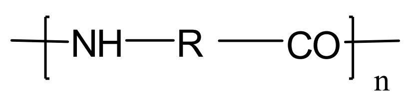


Nomenclature

- Polymerization of ethylene is called as 'poly(ethylene)' or polyethylene
- $-\!\!\left[CH_2 - CH_2 \right]_n\!\!-$ where n = degree of polymerization
- Similarly, polystyrene, polyamide, poly(vinyl chloride), poly(vinyl acetate), poly(methyl methacrylate) etc.



Polystyrene



Polyamide

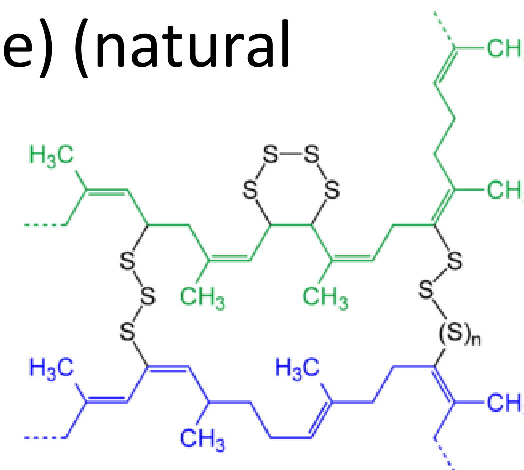
Classification of Polymers

Natural Polymers

- Nucleic acid, proteins, polysaccharides, polyprenes, cellulose and lignins etc.

Some semisynthetic polymers are made from natural polymers to make it more useful

- E.g., Cellulose acetate from cellulose
- Hardening of casein (a protein) by formaldehyde to galalith (plastic)
- Vulcanization of cis-1,4-poly(isoprene) (natural rubber) to an elastomer.



Vulcanization of isoprene

Application of some natural polymers

Name	Source	Application
Cellulose	Wood, cotton	Paper, clothing, rayon, cellophane
Starch	Potatoes, corn	Food, thickner
Wool	Sheep	Clothing
Silk	Silkworm	Clothing
Natural rubber	Rubber tree	Tires
Pitch	Oil deposits	Coating, roads

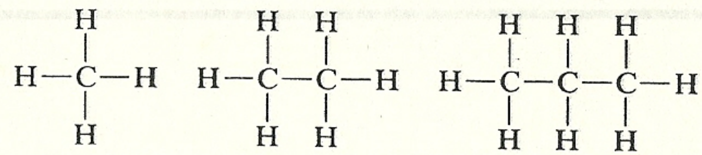
Synthetic polymers

Most of the polymers are synthesized from molecules with low molecular masses or its MONOMERS. The process is called POLYMERIZATION

e.g.

- Polystyrene from styrene
- Polyethylene from ethylene
- Poly(vinyl alcohol) from vinyl acetate
- Nylon 6 from ε-caprolactam
- Nylon 6, 6 from adipic acid and hexamethylene diamine
- Cellulose acetate from esterification of cellulose
- Poly(ethylene terephthalate) from esterification reaction between terephthalic acid and ethylene diol and transesterification between dimethyl terephthalate and ethylene diol

Small to big molecules



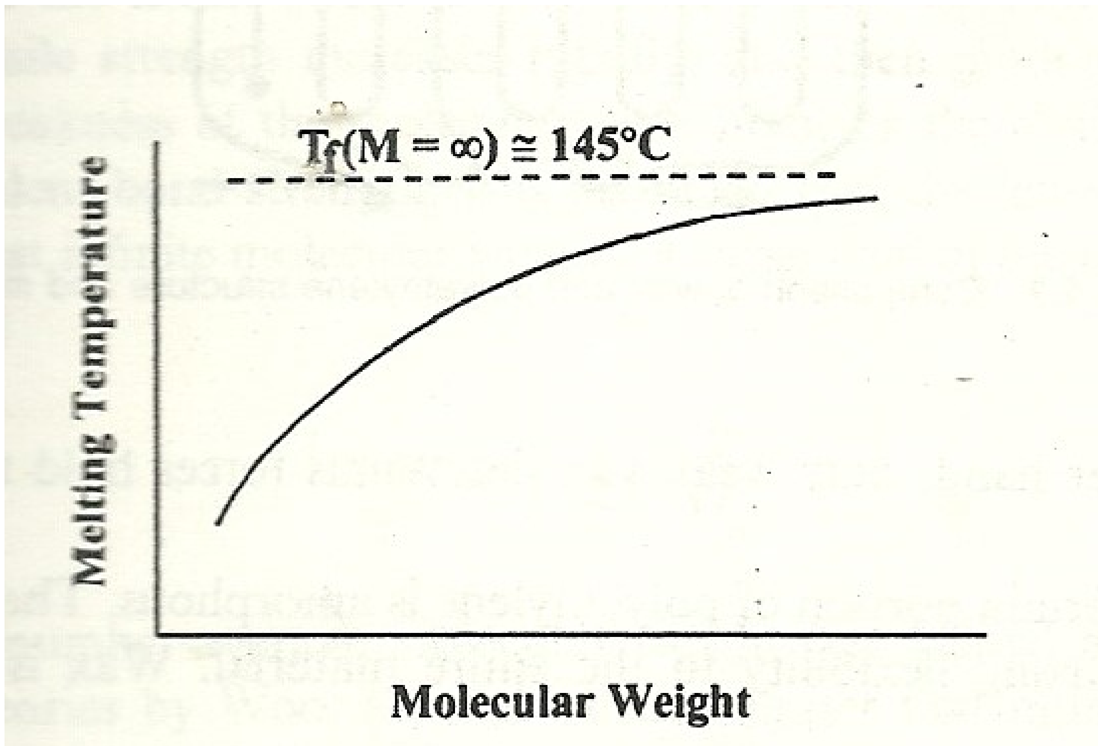
Methane Ethane Propane

These compounds have the general structure

$$H\left(CH_2\right)_nH$$

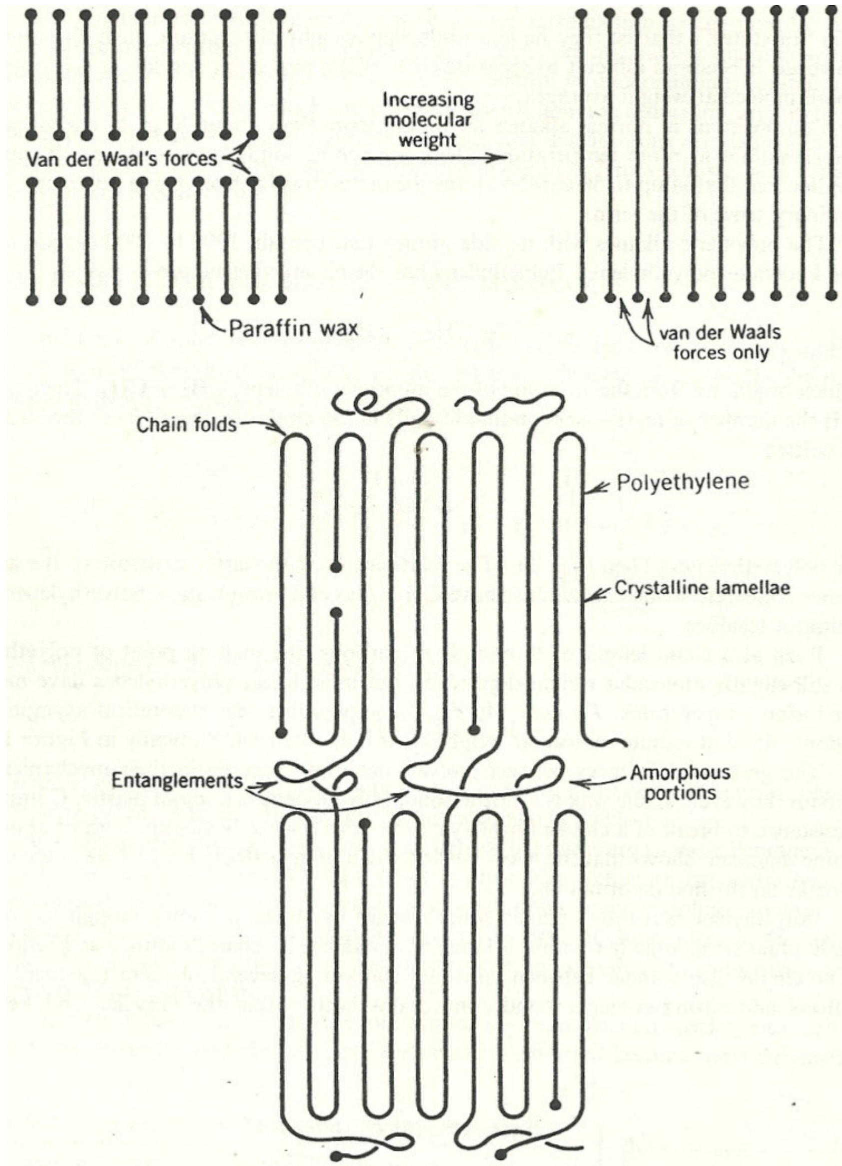
Number of carbons in chain	State and properties	Applications
1-4	Simple gas	Cooking gas
5-11	Simple liquid	Gasoline
9-16	Low-viscosity liquid	Kerosene
16-25	High-viscosity liquid	Oil and grease
25-50	Crystalline solid	Paraffin wax candles
50-1000	Semicrystalline solid	Milk carton adhesives and coatings
1000-5000	Tough plastic solid	Polyethylene bottles and containers
$3\text{-}6 * 10^5$	Fibers	Bullet-proof vests

Mol Wt. vs melting temp. for polyethylene



Crystalline

Semicrystalline



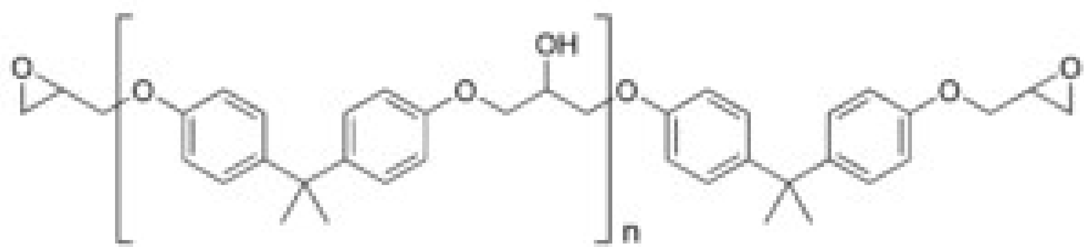
Comparison of wax and polyethylene structure and morphology

- Isotactic
- Syndiotactic
- Atactic

Plastics: Classifications

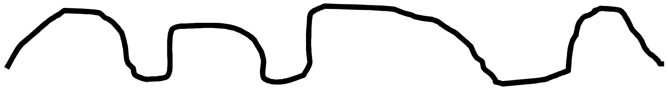
- Commodity thermoplastics
  - PVC, polyethylene, (high, low density) polypropylene, polystyrene etc.
- Engineering plastics
  - PET, poly(butylene terephthalate), polyamides, polycarbonate, poly(oxymethylene), PMMA, styrene/acrylonitrile (SAN), acrylonitrile/butadiene/styrene (ABS) etc.
- High-performance plastics
  - Liquid crystal polymers, polyether ketones, polysulfones, polyimides, kevlar etc.

- Functional plastics
  - Poly(ethylene-co-vinyl alcohol)
- Fluoroplastics
  - PTFE (teflon), poly(chlorotrifluoroethylene), poly(vinylidene fluoride) etc.
- Thermosets
  - Aklyd resins, phenolic resins, amino resins, epoxies, unsaturated polyesters, polyurethanes

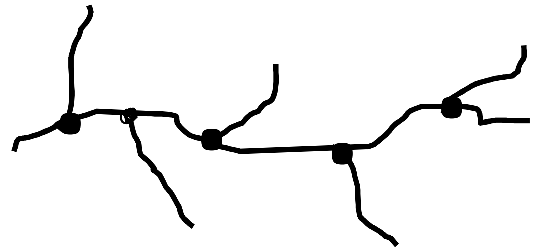


Epoxy or polyepoxide

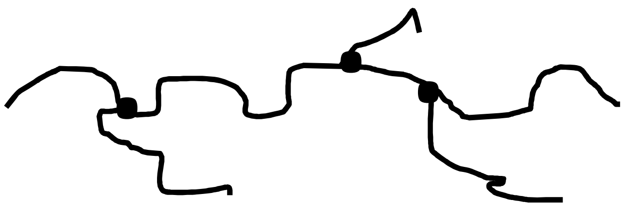
Linear, branched and crosslinked polymers



Linear polymer chain



Branched



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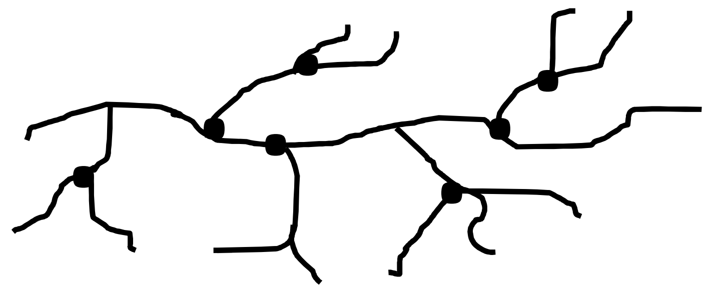

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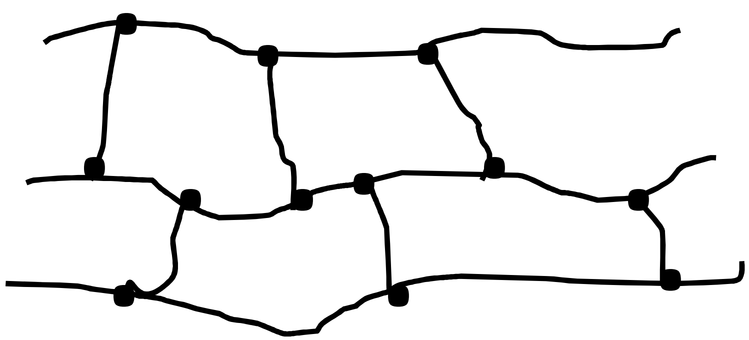

Crosslinked

Branching and crosslinking on properties

- Branching lowers the crystallinity of the polymer due to uneven packing in crystal lattice.
- T_g may be altered.
- Makes the polymer more rigid

Molecular forces and chemical bonding in polymers

- Primary bond
  - Ionic bond, e.g. NaCl
  - Covalent bond, e.g. CH_4
- Secondary bond forces
  - Van der Waals forces
  - Intermolecular forces
  - Hydrogen bond

Responsible for physical properties of polymers

Molecular weight

- Molecular weight of a polymer is an important aspect which determines most of the polymer properties, viz., mechanical, rheological and physical properties.
- Molecular weight of polymers show wide distribution, hence they are polydisperse in nature.
- Polydispersity can be determined using various molecular weights, viz., number average, weight average and viscosity average molecular weight.

Polymer mol. wt. vs. tensile strength

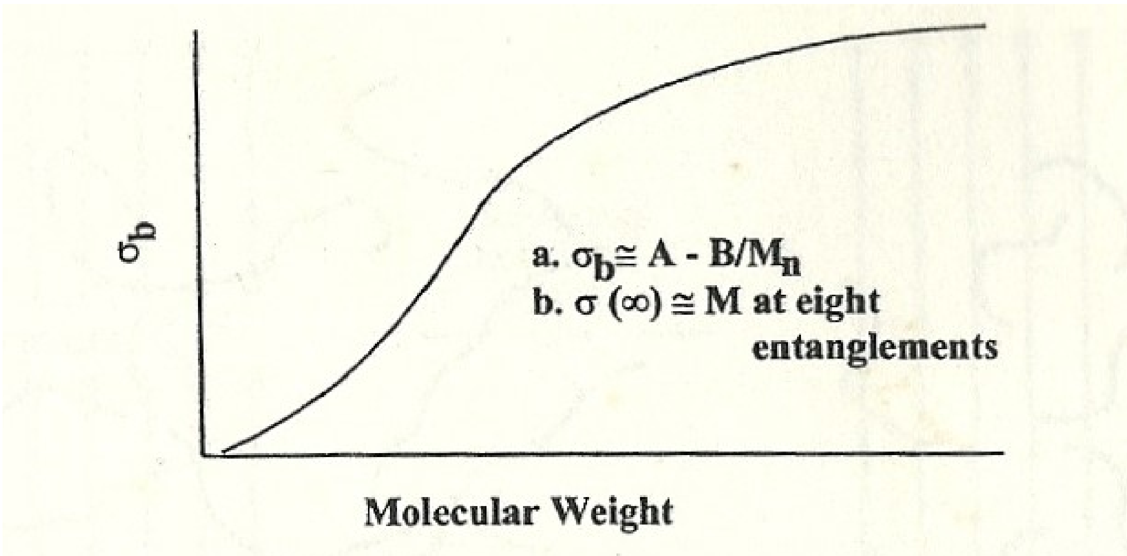

Figure 1.4 Effect of polymer molecular weight on tensile strength.

$$\sigma_b = A - \frac{B}{M_n}$$

Where σ_b = tensile strength, A is tensile strength at infinite mol wt. and B is a constant and M_n = mol wt.

Number average molecular weight (M_n)

Total weight of polymer divided by number of molecules

$$\text{Total weigth of the polymer} = \sum_{i=1}^{\infty} N_i M_i$$

$$\text{Total number of molecules} = \sum_{i=1}^{\infty} N_i$$

$$M_n = \frac{\sum_{i=1}^{\infty} N_i M_i}{\sum_{i=1}^{\infty} N_i} = \frac{\text{Total weight}}{\text{Number of polymers}} = \sum_{i=1}^{\infty} X_i M_i$$

$$\text{where, } X_i = \frac{N_i}{\sum N_i}$$

is number fraction or mole fraction of polymers