# TRIBOLOGY OF POLYMERS

**Tribology** is the science and engineering of rubbing surfaces.

**Polymer** is a substance (natural or synthetic), molecules of which consist of numerous small repeated chemical units (monomers) linked to each other in a regular pattern.

- **Advantages and disadvantages of polymers in tribological applications**
- **Polymer structure**
- **Viscoelasticity**
- **Surface energy**
- **Transfer film**
- **Wear of polymers**
- **Tribology of polymer composites**

## Advantages and disadvantages of polymers in tribological applications

Polymers are widely used in tribological applications due the following properties:

- Low coefficient of friction;
- High seizure resistance;
- Good chemical and corrosion resistance;
- Can be easily combined with other materials for fabrication Polymer Matrix Composites.

The disadvantages of polymers in tribological applications:

- Low thermal resistance;
- Low thermal conductivity;
- High Coefficient of Thermal Expansion;
- Low stiffness (modulus of elasticity);
- Low strength;
- Polymers swell in contact with Lubricants, water and other liquids.

## Polymer structure

Tribological properties of polymers are determined by the parameters and conditions of the polymer molecular structure:

- Length of the molecular chain;
- Molecular architecture (degree of branching);
- Cross-linking;
- Orientation of the molecules;

- Degree of crystallinity;
- Composition of the polymer blend;
- Chemical affinity to the material of the counterpart.

## Viscoalasticity

Behavior of polymers under mechanical loads is different from that
of Metals, Ceramics and Fluids.
Most of polymers are viscoelastic.

**Viscoelasticity** is the behavior of the deformed material, which combines the properties of both solid (elasticity) and liquid (viscosity).
The deformation (strain) of elastic materials is proportional to the load (stress) applied to the material. This linear function is time independent: strain forms instantly when the stress is applied. Ceramics and Metals at low temperature demonstrate elastic behavior below a certain level of strain (elasticity limit).
Viscous materials (liquids) resist fast deformation under the load. In contrast to an elastic material, which returns to its original shape immediately after the load is removed, a viscous material flows changing its dimensions for some time after changing the load (time dependent process).

Viscoelasticity of polymers plays an important role in their tribological behavior. The rubbing scratches on the polymer surface may heal due to the viscoelastic “flow” of the material.

## Surface energy

**Surface energy** is the energy required for a creation of a new surface.
Surface energy is summarized from the energies of the intermolecular bonds disrupted as a result of the surface creation.

Surface energy is the fundamental parameter determining the tribological properties of the material: coefficient of friction and wear resistance.
One of the Mechanisms of wear is the adhesive wear, which is a result of micro-junctions formed between the opposing asperities on the rubbing surfaces of the counterbodies. The load applied to the contacting asperities is so high that they deform and adhere to each other creating adhesive bonds. When the bonds break portions of the material are transferred to the counterface. This process includes disappear of some of the interfacial surface and creation of a new surface. The balance of the surface energies determines the adhesive wear process.

The effect of the surface energy on the coefficient of friction is also explained by the formation and disruption of the adhesive bonds between the rubbing surfaces. Lower surface energy results in lower coefficient of friction.

Surface energy of polymers is much lower than that of Ceramics and Metals.

## Transfer film

When a polymer material is rubbing against a harder material (e.g. metal) polymer particles are transferred to the metal countersurface and form a transfer film. Formation of the transfer film is determined by the relationship between the interfacial energy polymer-metal (adhesive work) and the polymer surface energy (cohesive work).

Transferred polymer fills the microdefects of the mating surface reducing its roughness, which results in lower coefficient of friction and wear. When a transfer film is formed the polymer part is rubbing against the polymer film on the metal counterpart and not against the metal itself. Due to the lower surface energy of polymers the coefficient of friction with the polymer transfer film is also lower.

## Wear of polymers

**Wear** is the removal of the material from the surface of a solid body as a result of mechanical action of the counterbody.

There are different mechanisms of wear of polymers:

- **Adhesive wear** is a result of micro-junctions caused by bonding between the opposing asperities on the rubbing surfaces of the counterbodies. The load applied to the contacting asperities is so high that they deform and adhere to each other forming the adhesion bonds. The motion of the rubbing counterbodies result in rupture of the micro-joints. The bonded polymer micro-asperities rupture and transfer onto the counterface.
- **Abrasive wear** is the wear of the softer material caused by the abrasion action of the harder material. The main mode of abrasive wear is cutting, during which a chip forms in front of the cutting asperity/grit. The material is removed (lost) from the surface of the wear track (groove). Ploughing is another mode of abrasion action, which in contrast to cutting does not result in wear (material loss). In ploughing the material is shifted to the sides of the wear groove. It is not removed from the surface. If there are only two rubbing parts involved in the friction process the wear is called two body wear. If the wear is caused by a hard particle (grit) trapped between the rubbing surfaces it is called three body wear.
- **Fatigue wear** of a material is caused by a cycling loading during friction. Fatigue cracks start at the material surface and spread to the subsurface regions. The cracks may connect to each other resulting in separation and delamination of the material pieces. Cycling loads applied to a polymer may also cause breaking the molecular chain in the surface layer, which results in a reduction of the degree of crystallinity.

- **Chemical wear** is a wear accelerated by chemical reactions occurring on the rubbing polymer surface.

## Tribology of polymer composites

Tribological properties of polymers may be significantly improved by dispersing filling materials throughout the polymer matrix (Polymer Matrix Composites).

Advantages of polymer composites:

- Lower coefficient of friction;
- Lower wear;
- Higher strength;
- Higher stiffness (modulus of elasticity);
- Higher thermal conductivity.

The polymers used as matrices for fabrication of sliding polymer composites:

- Polytetrafluoroethylene (PTFE)
- Epoxy (EP)
- Polyamides (PA)
- Ultra High Molecular weight Polyethylene (UHMWPE)
- Polyethereetherketone (PEEK)
- Polyoxymethylene(POM)

The fillers for fabrication of sliding polymer composites:

- Antifriction additives
  - Graphite;
  - Molybdenum disulfide;
  - Polytetrafluoroethylene (PTFE);
  - Liquid synthetic lubricants
- Thermal conductivity improves
  - Copper
  - Graphite

- Carbon fibers
- Reinforcing additives
  - Glass fibers
  - Carbon fibers
  - Kevlar (aramide) fibers
  - Ceramic (e.g. alumina, silicon carbide powder)

Source : http://www.substech.com/dokuwiki/doku.php?id=tribology_of_polymers