Discipline: Actual problems of chemistry of polymer composites

Lecture 10.

Theme: Manufacturing of Polymer Composites

Objective:

To understand the **methods and techniques for manufacturing polymer composites**, including the influence of processing parameters on **structure, properties, and performance**.

Key Questions:

1. What are the main manufacturing methods for polymer composites?
2. How do processing parameters affect composite quality?
3. What are the advantages and limitations of different manufacturing techniques?
4. How does reinforcement type and orientation influence the manufacturing process?
5. How are defects minimized during composite fabrication?

Lecture Content:

- **Overview of Polymer Composite Manufacturing:**
  - Polymer composites are made by **combining a polymer matrix with reinforcements** (fibers, particles, or fillers).
  - The goal is to produce a material with **enhanced mechanical, thermal, and functional properties**.
- **Classification of Manufacturing Methods:**
  1. **Molding Techniques:**
     - **Compression Molding:** Preheated polymer-resin and reinforcements are pressed into molds.
       - Advantages: simple, suitable for thermosets, good for large parts.
       - Limitations: slower cycle times, limited to moderate complexity.
     - **Injection Molding:** Polymer melt with or without fillers is injected into molds.

            - Advantages: high production rate, complex geometries possible.
            - Limitations: fiber breakage, uneven orientation of reinforcements.
        - **Transfer Molding:** Polymer is transferred into a mold under pressure.
            - Used for high-performance thermosetting composites.
    2. **Lay-Up Methods (for fiber-reinforced composites):**
        - **Hand Lay-Up:** Manual placement of fiber sheets and resin.
            - Advantages: simple, low-cost, flexible shapes.
            - Limitations: labor-intensive, variable quality.
        - **Spray-Up:** Chopped fibers and resin sprayed into molds.
            - Suitable for large structures but lower mechanical properties.
        - **Vacuum-Assisted or Resin Transfer Molding (VARTM/RTM):** Resin is drawn through fibers under vacuum.
            - Ensures uniform impregnation, reduces voids.
    3. **Extrusion and Pultrusion (for continuous fiber composites):**
        - **Extrusion:** Polymer-filler mixture is forced through a die to create continuous profiles.
        - **Pultrusion:** Continuous fibers are pulled through resin bath and heated die to produce strong composite rods or beams.
    4. **Calendering and Film Casting:**
        - Used for **thin sheets or films** of polymer composites.
        - Reinforcement may include nanofillers or platelets.
- **Influence of Reinforcement and Matrix on Manufacturing:**
    - Fiber type, length, and orientation influence **mechanical properties** and flow during molding.
    - Matrix viscosity affects **wetting, void formation, and surface finish**.
- **Processing Parameters:**
    - Temperature, pressure, curing time, and shear rates affect:
        - Degree of impregnation of fibers
        - Void content and density
        - Orientation and dispersion of fillers
        - Final mechanical and thermal properties
- **Defects and Quality Control:**
    - Common defects: voids, delamination, fiber misalignment, resin-rich or resin-poor areas.
    - Techniques to minimize defects: vacuum assistance, proper curing, surface treatment of fibers, optimized flow paths.
- **Applications:**
    - Aerospace: high-strength structural panels
    - Automotive: lightweight body parts
    - Construction: reinforced pipes, panels, and beams
    - Electronics: dielectric and thermal management components

Key Short Theses:

1. Manufacturing of polymer composites involves **combining matrix and reinforcement** to enhance properties.
2. Methods include **molding, lay-up, extrusion/pultrusion, and film casting**.
3. Processing parameters (temperature, pressure, shear) strongly influence **composite quality**.
4. Reinforcement type, size, orientation, and matrix viscosity determine **mechanical properties and defect formation**.
5. Defects such as **voids, delamination, and misalignment** reduce performance; vacuum and proper curing minimize them.
6. Each manufacturing method has **advantages and limitations** depending on part complexity, size, and required properties.
7. Optimized processing ensures **high-performance composites for aerospace, automotive, and industrial applications**.

Control Questions:

1. What are the main manufacturing methods for polymer composites?
2. How does fiber orientation affect the properties of composites during processing?
3. Compare compression molding and injection molding in terms of advantages and limitations.
4. What is the role of matrix viscosity in composite manufacturing?
5. Name common defects in polymer composites and ways to reduce them.
6. How do processing parameters influence final composite performance?
7. Which methods are best suited for continuous fiber composites?

Recommended references

Main literature:

1. Introduction to Polymer Science and Chemistry: A Problem-Solving Approach, Second Edition 2nd Edition / by Manas Chanda, CRC Press; 2nd edition (January 11, 2013)
2. Polymer Chemistry 2nd Edition / by Paul C. Hiemenz, Timothy P. Lodge, CRC Press; 2nd edition (February 15, 2007)
3. Semchikov Yu.D. High-molecular compounds: Textbook for universities. Moscow: Academy, 2003, 368.

4. S. Thomas, K. Joseph, S.K. Malhotra, K. Goda, M.S. Sreekala. Polymer composites. – Wiley-VCH, 2012. – 829 p.
5. Irmukhametova G.S. Fundamentals of polymer composite materials technology: textbook for universities; Al-Farabi Kazakh National University. - Almaty: Kazakh University, 2016. - 175 p.

Additional literature:

1. Polymer composite materials (part 1): a tutorial / L.I. Bondaletova, V.G. Bondaletov. - Tomsk: Publishing house of Tomsk Polytechnic University, 2013. - 118 p.
2. Polymer composite materials: structure, properties, technology. Edited by Berlin A.A. - St. Petersburg, Publishing house "Profession", 2008. - 560 p.
3. Polymer composite materials: structure, properties, technology: a tutorial / M.L. Kerber et al.; under the general editorship of A.A. Berlin. - St. Petersburg: Profession, 2009.- 556, [4] p.
4. Bataev, A.A. Composite materials. Structure, production, application: a tutorial. manual / A. A. Bataev, V. A. Bataev. - M.: Logos, 2006. - 397, [3] p. - (New University Library).