

Q.1.i. Between a 9 Denier fully drawn circular polyester fibre and a 9 denier fully drawn circular polypropylene fibre which one is thicker? Justify your answer. Why surface treatment of carbon fibres is required? Explain.

- Between a 9 Denier fully drawn circular polyester fibre and a 9 denier fully drawn circular polypropylene fibre, the **polypropylene fibre will be thicker**.
- **Justification:** Denier is a measure of linear density, defined as the weight in grams of 9,000 meters of fibre. Therefore, for the same denier, the fibre with a lower density will have a larger cross-sectional area (and thus be thicker). Polyester has a density of approximately  $1.38 \text{ g/cm}^3$ , while polypropylene has a density of approximately  $0.91 \text{ g/cm}^3$ . Since polypropylene is less dense than polyester, a given weight of polypropylene will occupy a larger volume, making its fibre thicker for the same denier.
- **Why surface treatment of carbon fibres is required?**
  - **Improved Adhesion:** Carbon fibres inherently have a smooth, inert surface, which leads to poor adhesion with matrix resins in composites. Surface treatment creates functional groups (e.g., carboxyl, hydroxyl, carbonyl) and increases surface roughness, enhancing mechanical interlocking and chemical bonding between the fibre and the matrix.
  - **Stress Transfer:** Better adhesion allows for more efficient transfer of stress from the matrix to the high-strength carbon fibres, thereby maximizing the composite's mechanical properties, such as tensile strength and interlaminar shear strength.
  - **Wettability:** Surface treatments improve the wettability of carbon fibres by the resin, ensuring better impregnation and reducing voids in the composite.
  - **Interfacial Shear Strength:** It significantly increases the interfacial shear strength, which is crucial for the overall performance and durability of carbon fibre composites.

ii. Discuss significance of tensile force on fibre during melt spinning.

- **Significance of Tensile Force on Fibre during Melt Spinning:**

- **Molecular Orientation:** Tensile force, also known as draw-down force, is applied to the molten filament as it exits the spinneret. This force stretches the polymer chains, causing them to align in the direction of the fibre axis. This molecular orientation is crucial for developing high tensile strength and modulus in the final fibre.
- **Crystallization and Structure Development:** The applied tension influences the rate and type of crystallization that occurs as the polymer cools. It can promote the formation of more ordered crystalline regions and improve the overall degree of crystallinity, leading to enhanced mechanical properties.
- **Fibre Fineness and Uniformity:** The tensile force controls the final diameter (fineness) of the fibre. By varying the draw-down ratio (ratio of take-up speed to extrusion speed), the denier of the fibre can be precisely controlled. Consistent application of tensile force ensures uniform fibre diameter along its length, which is vital for subsequent processing and end-use performance.
- **Reduction of Defects:** Proper tensile force helps in consolidating the molten stream, reducing the likelihood of voids, air bubbles, and other structural defects that can weaken the fibre.
- **Controlling Mechanical Properties:** The extent of molecular orientation induced by tensile force directly impacts properties such as tensile strength, elongation at break, and toughness. Higher orientation generally leads to higher strength and modulus but lower elongation.

iii. Illustrate Degree of order and molecular extent in fibres.

- **Degree of Order in Fibres:**

- The degree of order refers to the extent to which polymer chains in a fibre are aligned and packed in a regular, crystalline arrangement.

- Fibres are typically semicrystalline, meaning they contain both crystalline (ordered) and amorphous (disordered) regions.
- In crystalline regions, polymer chains are highly aligned, closely packed, and exhibit long-range order, similar to a crystal lattice. These regions contribute significantly to the fibre's strength, stiffness, and dimensional stability.
- In amorphous regions, the polymer chains are randomly coiled and entangled, lacking any regular arrangement. These regions contribute to the fibre's flexibility, elasticity, and dye uptake.
- The "degree of order" is a quantitative measure of the proportion of crystalline material within the fibre. A higher degree of order generally correlates with higher tensile strength, modulus, and density, but potentially lower elongation and dyeability.
- **Molecular Extent in Fibres:**
  - Molecular extent refers to the overall length and alignment of individual polymer chains within the fibre structure.
  - It describes how much the long polymer molecules are stretched out and oriented parallel to the fibre axis.
  - During fibre formation processes like drawing or stretching, the entangled polymer chains are pulled and extended, reducing their random coil conformation and increasing their molecular extent along the fibre direction.
  - A greater molecular extent implies a higher degree of chain extension and parallel alignment, which allows for more efficient load bearing along the fibre length.
  - This increased molecular extent is directly responsible for the high tensile strength and modulus observed in high-performance fibres, as it maximizes the contribution of the strong covalent bonds along the polymer backbone.

iv. Distinguish primary cellulose acetate fibre and secondary cellulose acetate fibre.

- **Primary Cellulose Acetate Fibre:**

- **Degree of Acetylation:** Typically refers to cellulose triacetate, where nearly all (at least 92%) of the hydroxyl groups on the anhydroglucose units are acetylated. This means three acetate groups are substituted per anhydroglucose unit.
- **Solubility:** Soluble in specific solvents like dichloromethane (methylene chloride).
- **Properties:** Possesses a higher melting point, lower moisture regain, and improved dimensional stability compared to secondary cellulose acetate. It has a silkier feel and greater resistance to creasing.
- **Dyeability:** More difficult to dye due to its lower polarity and fewer available hydroxyl groups. Requires disperse dyes.

- **Secondary Cellulose Acetate Fibre:**

- **Degree of Acetylation:** Refers to cellulose diacetate, where approximately 2.0 to 2.5 hydroxyl groups per anhydroglucose unit are acetylated (typically around 53-56% acetyl content). It is partially hydrolyzed from cellulose triacetate.
- **Solubility:** Soluble in common organic solvents like acetone.
- **Properties:** Has a lower melting point, higher moisture regain, and less dimensional stability than primary cellulose acetate. It is softer and drapes well.
- **Dyeability:** Easier to dye than cellulose triacetate due to the presence of more free hydroxyl groups, allowing it to be dyed with disperse dyes and some acid dyes.

v. Illustrate Spin-stretch during coagulation in wet spinning.

- **Spin-stretch during Coagulation in Wet Spinning:**

- In wet spinning, a polymer solution (dope) is extruded through a spinneret into a coagulation bath, where the polymer precipitates and solidifies to form a filament.
- **Spin-stretch** refers to the drawing or stretching of the nascent fibre as it is being formed and solidified within the coagulation bath, and immediately after exiting it, before it is fully solidified.
- As the polymer solution enters the coagulation bath, solvent diffuses out of the filament and non-solvent diffuses in, causing the polymer to precipitate. During this process, the fibre is still in a gel-like or highly plasticized state.
- A tension is applied to the emerging fibre by the take-up rollers, which are typically running at a higher speed than the extrusion rate from the spinneret. This difference in speed applies the spin-stretch.
- **Effect:** This stretching aligns the polymer chains along the fibre axis while they are still mobile within the nascent structure. This immediate orientation locks in a significant degree of molecular alignment even before further solid-state drawing.
- **Significance:** Spin-stretch is crucial for developing initial molecular orientation and promoting the formation of a highly ordered structure in wet-spun fibres. It contributes significantly to the final mechanical properties, such as tensile strength and modulus, by pre-orienting the polymer chains and influencing the morphology of the nascent fibre. It also helps control the fibre's fineness.

Q.2.a) Discuss properties and applications of PAN fibres.

- **Properties of PAN (Polyacrylonitrile) Fibres:**

- **High Tensile Strength and Modulus:** PAN fibres exhibit excellent strength and stiffness, especially when highly oriented.
- **Good Crease Resistance:** They maintain their shape well and resist wrinkling.

- **Excellent Lightfastness:** PAN fibres are highly resistant to degradation from sunlight, making them suitable for outdoor applications.
- **Good Chemical Resistance:** They are resistant to many acids, alkalis, and solvents, although strong oxidizing agents can degrade them.
- **Low Moisture Regain:** PAN fibres absorb very little moisture, which can lead to static electricity buildup but also contributes to quick drying.
- **Soft Hand and Good Drape:** Acrylic fibres (made from PAN) are known for their soft, wool-like feel and good draping characteristics, especially in staple form.
- **Good Thermal Stability:** While they do not melt, they char upon heating, which is a critical property for their use as a precursor for carbon fibres.
- **Resistance to Moths, Mildew, and Fungi:** Their synthetic nature makes them inhospitable to biological attack.
- **Fair Abrasion Resistance:** They hold up reasonably well to rubbing and wear.
- **Applications of PAN Fibres:**
  - **Carbon Fibre Precursors:** This is by far the most significant application. Over 90% of all carbon fibres are produced from PAN precursors due to PAN's high carbon yield, excellent mechanical properties after carbonization, and ability to form an oriented structure.
  - **Apparel and Textiles (Acrylic Fibres):** In staple form, PAN fibres are widely used in sweaters, socks, blankets, knitwear, and simulated fur fabrics, often blended with wool or other fibres, due to their soft feel, warmth, and resilience.

- **Outdoor Fabrics:** Due to their excellent UV resistance, they are used in awnings, tents, outdoor furniture fabrics, and boat covers.
- **Industrial Applications:** Ropes, carpets, filtration media, and reinforcing fibres in various composites.
- **Filtration:** Due to chemical resistance and good filtration properties, they are used in industrial filters.
- **Upholstery:** Their durability and resistance to fading make them suitable for furniture upholstery.

b) If you have a polymer that can be spun by both melt spinning and wet spinning. And you want to prepare a high-performance fibre. Which spinning process you will choose and why?.

- If I had a polymer that could be spun by both melt spinning and wet spinning, and my goal was to prepare a high-performance fibre, I would likely choose **wet spinning**.
- **Justification:**
  - **Higher Molecular Orientation during Coagulation:** Wet spinning allows for significant molecular orientation to be locked into the fibre during the coagulation and drawing process, while the polymer is still in a plasticized or gel-like state. This "spin-stretch" or "gel-drawing" can achieve very high levels of molecular alignment and chain extension that are difficult to attain in melt spinning without breaking the fibre.
  - **Control over Morphology:** Wet spinning offers greater control over the internal microstructure and morphology of the fibre. By manipulating parameters such as solvent composition, coagulation bath temperature, and draw ratio in the bath, specific crystalline forms and void structures can be engineered, which are critical for high-performance applications (e.g., formation of fibrils).
  - **Suitable for High Molecular Weight Polymers:** Many high-performance polymers have very high molecular weights, which

results in extremely high melt viscosities. Such high viscosities make melt spinning impractical or impossible due to excessive processing temperatures or degradation. Wet spinning, which uses a polymer solution, circumvents this issue.

- **Avoidance of Thermal Degradation:** High-performance polymers often have limited thermal stability. Melt spinning requires heating the polymer above its melting point, which can lead to thermal degradation, chain scission, and loss of properties. Wet spinning operates at much lower temperatures, minimizing the risk of thermal damage.
- **Formation of Complex Structures:** Certain high-performance fibres, like aramid fibres (e.g., Kevlar, Nomex), form liquid crystalline solutions, which are essential for achieving their exceptional properties. Wet spinning is the ideal method to process such solutions and preserve their ordered structure.

Q.2.a) How would you prepare of high tenacity and high wet modulus rayon.? Also illustrate their properties.

- **Preparation of High Tenacity (HT) and High Wet Modulus (HWM) Rayon:**
  - Both HT and HWM rayon are regenerated cellulose fibres, typically produced via the viscose process, but with significant modifications to achieve enhanced properties.
  - **Key Principles for High Performance:** The main aim is to increase the degree of polymerization (DP), enhance molecular orientation, and improve crystallinity, while minimizing defects and maintaining a uniform structure.
  - **Preparation Steps for HT Rayon (Tire Cord Rayon):**
    1. **High-Quality Pulp:** Start with high-alpha cellulose wood pulp to ensure a high initial degree of polymerization and purity.



2. **Special Viscose Composition:** Use a viscose dope with a lower cellulose content (e.g., 5-7%) and a higher NaOH concentration (e.g., 6-7%) compared to regular rayon. Also, include additives like zinc sulfate ( $\text{ZnSO}_4$ ) in the spin bath.

3. **Two-Bath Spinning Process:**

- **First Bath (Regeneration):** The viscose is extruded into a highly acidic (e.g.,  $\text{H}_2\text{SO}_4$ ) and zinc sulfate-containing bath. The zinc ions act as a coagulant and retardant, leading to slower, more uniform coagulation and primary regeneration of cellulose xanthate. This slow coagulation allows for more extensive stretching.
- **Second Bath (Drawing/Stretching):** The partially regenerated filament is then drawn extensively in a second, hotter, dilute acidic bath (e.g., boiling water or dilute  $\text{H}_2\text{SO}_4$ ). This "hot stretch" is critical. The high temperature allows the polymer chains to be highly oriented and aligned before full regeneration and crystallization occur.

4. **Extensive Drawing:** The draw ratio is significantly higher than for regular rayon (e.g., 100-200% stretch), leading to highly oriented polymer chains.

5. **Washing, Desulfurization, and Drying:** Standard finishing steps follow.

○ **Preparation Steps for HWM Rayon (Polynosic Rayon):**

1. **High-Quality Pulp and Viscose:** Similar to HT rayon, use high-quality pulp and a carefully controlled viscose composition, often with a higher degree of polymerization of the cellulose xanthate.
2. **Modified Spin Bath:** The coagulation bath is typically less acidic and contains a lower concentration of sodium sulfate

compared to regular viscose rayon. Critically, it contains **retardants** (e.g., amine compounds, polyethylene glycol) that slow down the regeneration process.

3. **High Stretch Ratio in Coagulation:** The filament is subjected to a very high degree of stretch (often 100-150%) *within* the coagulation bath, before full regeneration. The retardants ensure that the fibre remains plastic and can be stretched significantly without breaking.
4. **Delayed Regeneration:** The slow and controlled regeneration allows the polymer chains to align extensively under tension, promoting the formation of a more uniform, highly oriented structure with a high degree of crystallinity.
5. **Controlled Washing and Drying:** Careful washing to remove impurities and controlled drying to maintain the developed structure.

- **Properties of High Tenacity (HT) Rayon:**

- **High Tensile Strength:** Significantly higher dry and wet tensile strength than regular rayon (e.g., 5.0-7.0 g/den dry, 3.5-5.0 g/den wet).
- **High Modulus:** Stiffer and more resistant to deformation.
- **Lower Elongation at Break:** Less stretchy than regular rayon.
- **Good Fatigue Resistance:** Important for applications requiring repeated stress.
- **Reduced Swelling:** Exhibits less swelling in water compared to regular rayon.
- **Applications:** Primarily used in tire cords for vehicles, industrial belts, hoses, and other reinforcing applications where high strength and fatigue resistance are crucial.

- **Properties of High Wet Modulus (HWM) Rayon:**

- **High Wet Modulus:** Crucially, it retains a high percentage of its strength and stiffness when wet, much more so than regular rayon. This is its defining characteristic.
- **Good Dry and Wet Strength:** Possesses good overall strength (e.g., 4.0-5.5 g/den dry, 2.5-4.0 g/den wet), though typically slightly lower than HT rayon.
- **Excellent Dimensional Stability:** Exhibits minimal shrinkage or stretching when wet, similar to cotton.
- **Good Resilience:** Resists creasing and recovers well from deformation.
- **Cotton-like Properties:** Often described as having properties closer to cotton than regular rayon, including good absorbency, breathability, and dyeability.
- **Good Drape and Soft Hand:** Retains the comfortable feel and good draping characteristics of regenerated cellulose.
- **Applications:** Widely used in apparel (shirts, dresses, workwear), home furnishings (sheets, towels), and blends with cotton or synthetic fibres where durability, wet strength, and dimensional stability are desired. It can be mercerized like cotton.

Q.3.a) Compare and contrast the formation mechanisms of PAN-based carbon fibres and pitch-based carbon fibres. Explain how these differences affect the properties and applications of the resulting fibres.

- **Comparison and Contrast of Formation Mechanisms:**
  - **PAN-based Carbon Fibres:**
    - **Precursor:** Polyacrylonitrile (PAN) fibre.
    - **Stabilization (Oxidative Thermosetting):** The crucial first step (200-300 °C in air) where PAN fibres are heated in an oxidizing atmosphere. This causes cyclization and cross-linking of the polymer chains, converting the linear thermoplastic PAN

into a ladder-like, infusible, and thermally stable structure. This process is slow and determines the ultimate mechanical properties.

- **Carbonization:** The stabilized fibres are then heated to higher temperatures (1000-1500 °C) in an inert atmosphere (nitrogen) to remove non-carbon elements (H, N, O) and form a turbostratic graphite structure. Significant weight loss occurs.
  - **Graphitization (Optional):** For ultra-high modulus fibres, carbonized fibres are heated to even higher temperatures (2000-3000 °C) in an inert atmosphere, promoting further ordering and growth of graphite crystallites.
  - **Yield:** Generally good carbon yield (approx. 50-60%).
- **Pitch-based Carbon Fibres:**
- **Precursor:** Petroleum pitch or coal tar pitch (by-products of petroleum refining or coal processing).
  - **Melt Spinnability:** Pitch is a thermoplastic material that can be melt-spun into fibres.
  - **Infusibilization/Stabilization:** The spun pitch fibres must be made infusible. This is achieved by heating them in an oxidizing atmosphere (250-400 °C in air). This causes cross-linking of the aromatic molecules in the pitch, forming a stable, solid, and non-melting structure. This step is critical to prevent melting during carbonization.
  - **Carbonization:** The stabilized pitch fibres are heated to high temperatures (1000-2000 °C) in an inert atmosphere, removing volatile components and forming a carbon structure.
  - **Graphitization (Crucial for High Performance):** Pitch-based fibres are typically graphitized at very high temperatures (2000-3000 °C) to achieve high modulus. The inherent anisotropic

nature of mesophase pitch allows for the formation of highly ordered graphitic structures upon graphitization.

- **Yield:** Can have very high carbon yield (up to 90%).

- **How Differences Affect Properties and Applications:**

- **Molecular Structure and Anisotropy:**

- **PAN-based:** The ladder polymer structure formed during stabilization leads to a **turbostratic graphitic structure** with some degree of preferred orientation, resulting in excellent tensile strength and good modulus. The strength arises from the inherent chain strength and orientation.
    - **Pitch-based:** The highly aromatic nature of pitch, especially mesophase pitch, leads to a **highly anisotropic, layered graphitic structure** that can achieve extremely high modulus upon graphitization. The orientation of these graphene layers along the fibre axis is key.

- **Mechanical Properties:**

- **PAN-based:** Generally exhibit **superior tensile strength** and good to excellent modulus. They are the workhorse for high-strength applications.
    - **Pitch-based:** Can achieve **ultra-high modulus** (even higher than PAN-based) but often have lower tensile strength, especially isotropic pitch fibres. Mesophase pitch fibres can achieve very high modulus and good strength.

- **Cost:**

- **PAN-based:** Higher precursor cost and more complex, time-consuming stabilization process contribute to their generally **higher cost**.
    - **Pitch-based:** Lower precursor cost (by-product) and potentially simpler processing for isotropic fibres make them generally

**lower cost**, especially for general-purpose grades. However, high-modulus mesophase pitch fibres can also be expensive due to the demanding graphitization process.

- **Applications:**

- **PAN-based:** Dominant in **structural composites** where high strength-to-weight ratio is critical, such as aerospace (aircraft components, satellites), sporting goods (golf clubs, fishing rods, bicycles), automotive, and wind turbine blades.
- **Pitch-based:**
  - **Isotropic Pitch:** Used in **lower-performance applications** like friction materials, insulation, battery electrodes, and as general-purpose conductive fillers due to their lower cost.
  - **Mesophase Pitch:** Utilized in **high-modulus, high-thermal conductivity applications** where stiffness and heat dissipation are paramount, such as aerospace brake materials, thermal management systems, and specialized sporting goods. They are also used where electrical conductivity is important.

b) Compare the formation mechanisms and resulting properties of Rockwool, and Glass fibres.

- **Rockwool (Mineral Wool / Stone Wool):**

- **Formation Mechanism:**

1. **Raw Materials:** Basalt, diabase, or other igneous rocks, along with coke (as fuel) and sometimes recycled slag from other industries.
2. **Melting:** The raw materials are melted in a cupola furnace or electric furnace at very high temperatures (around 1500-1600 °C) to form a molten slag.

3. **Fibre Formation (Centrifugal Spinning):** The molten slag flows onto rapidly rotating multi-roller spinning wheels or is blown by a high-velocity air stream. The molten material is flung outwards, forming thin streams that are rapidly stretched and cooled by air, solidifying into long, fine, entangled fibres.
  4. **Binder and Curing:** A small amount of binder (e.g., phenolic resin) and mineral oil (for dust reduction and water repellency) are sprayed onto the fibres.
  5. **Collection and Curing:** The fibres are collected as a mat, compressed, and passed through an oven to cure the binder, forming rigid or semi-rigid boards, mats, or batts.
- **Resulting Properties:**
    - **Excellent Thermal Insulation:** Due to its open, entangled fibrous structure that traps air, it is highly effective at reducing heat transfer.
    - **Excellent Fire Resistance:** Non-combustible, with a very high melting point. It can withstand temperatures up to 1000 °C, making it a crucial fire barrier material.
    - **Good Acoustic Absorption:** Its porous structure effectively absorbs sound, reducing noise transmission.
    - **Water Repellent:** Often treated to be hydrophobic, preventing water absorption.
    - **Rot and Vermin Proof:** Inorganic nature makes it resistant to biological degradation.
    - **Relatively Low Mechanical Strength:** Individual fibres are brittle, and bulk products are generally not load-bearing but rather used for insulation.
    - **Density:** Available in various densities for different applications.

- **Glass Fibres:**

- **Formation Mechanism:**

1. **Raw Materials:** Silica sand, limestone, soda ash, borax, etc., forming specific glass compositions (e.g., E-glass, S-glass, A-glass, C-glass).
2. **Melting:** Raw materials are melted in a high-temperature furnace (around 1300-1500 °C) to form molten glass.
3. **Fibre Formation (Continuous Filament or Staple Fibre):**
  - **Continuous Filament (Most Common for Composites):** Molten glass flows through small orifices (bushings) in a platinum alloy plate. Filaments are pulled downwards at high speed by a winding mechanism, rapidly attenuating and cooling them into continuous strands. A sizing agent is applied.
  - **Staple Fibre (for Insulation, etc.):** Molten glass is attenuated by high-velocity steam or air jets, or by being spun off rapidly rotating discs, creating discontinuous, shorter fibres which are then collected.
4. **Sizing/Finishing:** A chemical sizing agent (containing coupling agents, lubricants, film formers) is applied to protect the fibres, improve handling, and promote adhesion with matrix resins in composites.
5. **Drying and Winding:** Continuous filaments are wound onto bobbins, while staple fibres are collected in various forms.

- **Resulting Properties:**

- **High Tensile Strength:** Especially when made as continuous filaments, they exhibit excellent specific strength (strength-to-weight ratio).
- **High Modulus/Stiffness:** Good rigidity.



- **Non-Combustible:** Inherently fire resistant.
  - **Excellent Electrical Insulator:** Widely used in electrical applications.
  - **Good Chemical Resistance:** Resistant to most chemicals, though strong alkalis and hydrofluoric acid can attack them.
  - **Low Thermal Expansion:** Good dimensional stability.
  - **Brittleness:** Inherently brittle, making them susceptible to damage if not handled carefully, especially when not within a matrix.
  - **Poor Abrasion Resistance (Unsize):** Individual fibres can abrade against each other, leading to strength loss if not protected by sizing.
  - **Transparency:** Optical properties allow for light transmission.
  - **Inorganic and Non-biodegradable:** Resistant to rot, mildew, and insects.
- **Key Differences Summary:**
- **Raw Materials:** Rockwool uses igneous rocks/slag; Glass fibres use silica sand, limestone, etc.
  - **Primary Application:** Rockwool for insulation (thermal/acoustic) and fire protection; Glass fibres for reinforcement in composites, electrical insulation.
  - **Form:** Rockwool is typically discontinuous, entangled, and used in mats/boards; Glass fibres can be continuous filaments or staple, depending on application.
  - **Microstructure:** Rockwool has a more random, entangled structure; Glass fibres, especially continuous filaments, have a more uniform, cylindrical structure.

- **Mechanical Properties:** Glass fibres are engineered for high tensile strength and stiffness in composites; Rockwool for bulk insulation properties.

c) Why cotton fibres gain strength when wet? And which features of cotton fibre contribute to its relatively easy dyeability despite its high crystallinity?.

- **Why cotton fibres gain strength when wet?**
  - **Increased Hydrogen Bonding:** When cotton fibres become wet, water molecules penetrate the amorphous regions and, to some extent, the less ordered crystalline regions between the cellulose chains. This allows the cellulose molecules to swell and move closer together in certain areas. As water plasticizes the amorphous regions, the chains can reorient slightly, and new hydrogen bonds can form between adjacent cellulose molecules, both directly and indirectly via water molecules acting as bridges. These additional hydrogen bonds increase the cohesive forces within the fibre structure.
  - **Removal of Stress Concentrations:** In a dry state, the presence of micro-voids and imperfections (dislocations, chain ends) within the fibre structure can act as stress concentration points, leading to premature failure. When wet, the swelling action of water helps to fill some of these voids and reduce these stress concentrations, allowing the fibre to distribute stress more evenly and bear a higher load before breaking.
  - **Plasticizing Effect:** Water acts as a plasticizer for the amorphous regions of cellulose. This makes the fibre more flexible and ductile when wet, allowing it to undergo more deformation before fracture. While extensibility increases, the overall effect of increased hydrogen bonding and reduced stress concentrations leads to a net gain in tenacity.
- **Which features of cotton fibre contribute to its relatively easy dyeability despite its high crystallinity?**

- **Hydroxyl Groups:** Cotton fibre (cellulose) has a large number of readily accessible hydroxyl (-OH) groups on its glucose units. These hydroxyl groups are highly polar and can readily interact with water and dye molecules through hydrogen bonding and dipole-dipole interactions. Many common dyes (e.g., direct, reactive, vat dyes) form strong bonds or associations with these hydroxyl groups.
- **Capillary Structure and Porosity:** Despite its high overall crystallinity (around 60-80%), cotton fibre has a complex hierarchical structure. It contains significant amorphous regions, an extensive network of sub-microscopic capillaries, and a lumen (central canal). This internal porosity and capillary network allow water and dye molecules to penetrate deeply into the fibre structure, reaching a large surface area for dye absorption and reaction.
- **Swelling in Water:** Cotton swells significantly in water. This swelling opens up the amorphous regions and expands the accessible pores and capillaries, making it easier for dye molecules to diffuse into the fibre. The increased accessibility allows for more efficient interaction between the dye and the cellulose macromolecules.
- **Negative Zeta Potential:** In aqueous solutions, cellulose fibres develop a negative surface charge (zeta potential). This can be advantageous for the adsorption of positively charged dye molecules (cationic dyes, although not primary for cotton) or for promoting the diffusion of anionic dyes into the fibre by electrostatic repulsion from the bulk solution towards the fibre surface (though specific mechanisms vary by dye class).
- **Reactivity:** For reactive dyes, the hydroxyl groups on cellulose can chemically react with the dye molecules, forming strong covalent bonds that make the dyeing permanent and wash-fast. This inherent chemical reactivity is a key feature.

d) Explain swelling of fibres.

- **Swelling of Fibres:**

- Swelling refers to the increase in volume or dimensions (length, diameter) of a fibre when it absorbs a liquid, typically water or a specific solvent. This phenomenon is a result of the penetration of liquid molecules into the fibre's internal structure.
- **Mechanism:**
  1. **Diffusion:** Liquid molecules diffuse from the surrounding medium into the fibre structure, initially entering the more accessible, disordered (amorphous) regions.
  2. **Interaction:** These liquid molecules interact with the polymer chains within the fibre, primarily through hydrogen bonding or other intermolecular forces. In hydrophilic fibres like cotton, water molecules form hydrogen bonds with the hydroxyl groups of cellulose.
  3. **Chain Separation:** As liquid molecules associate with the polymer chains, they effectively push the chains further apart. This acts to disrupt the secondary intermolecular forces (like van der Waals forces or existing hydrogen bonds) that hold the polymer chains together in the dry state.
  4. **Volume Increase:** The separation of polymer chains leads to an increase in the free volume within the fibre, causing it to expand in volume and dimensions.
  5. **Amorphous vs. Crystalline:** Swelling primarily occurs in the amorphous regions of the fibre, where the polymer chains are less ordered and more accessible. Crystalline regions, with their tightly packed and highly ordered structures, are much more resistant to swelling as it is difficult for liquid molecules to penetrate them. The degree of swelling is inversely related to the degree of crystallinity.
- **Factors Affecting Swelling:**

- **Fibre Type:** Hydrophilic fibres (e.g., cotton, rayon, wool, silk) swell significantly in water due to abundant polar groups. Hydrophobic fibres (e.g., polyester, polypropylene) swell very little in water.
- **Degree of Crystallinity:** Lower crystallinity generally leads to higher swelling.
- **Chemical Structure:** Presence of polar groups (hydroxyl, amide, carboxyl) increases affinity for polar solvents.
- **Cross-linking:** Higher degree of cross-linking restricts chain movement and reduces swelling.
- **Temperature:** Higher temperatures generally increase the rate and extent of swelling.
- **Liquid Nature:** The type of liquid (solvent vs. non-solvent) and its compatibility with the fibre polymer.
- **Significance:**
  - **Dyeing and Finishing:** Swelling opens up the fibre structure, allowing dyes and chemical finishes to penetrate more effectively.
  - **Dimensional Stability:** Excessive swelling can lead to undesirable shrinkage or distortion upon drying, impacting fabric dimensions.
  - **Mechanical Properties:** Swelling can alter mechanical properties; for instance, cotton gains strength when wet, while some synthetic fibres lose strength.
  - **Comfort:** Water absorption and swelling contribute to the comfort of natural fibres by wicking away moisture.

Q.4.a) Explain mechanical properties of nylons.

- **Mechanical Properties of Nylons (Polyamides):**

- Nylons are synthetic thermoplastic polymers known for their excellent balance of strength, toughness, and elasticity. Their properties can vary significantly depending on the specific type of nylon (e.g., Nylon 6, Nylon 6,6, Nylon 6,10), molecular weight, degree of polymerization, crystallinity, and processing conditions (e.g., drawing).
- **Key Mechanical Properties:**
  1. **High Tensile Strength:** Nylons possess high tensile strength, meaning they can withstand significant pulling forces before breaking. This is due to strong hydrogen bonding between the amide groups of adjacent polymer chains and the ability of the long chains to align under stress. Highly drawn nylon fibres can achieve very high strength.
  2. **Good Toughness/Impact Resistance:** Nylons are very tough and resilient, meaning they can absorb a considerable amount of energy before fracturing. This property is particularly valuable in applications requiring resistance to sudden impacts or repeated stress. Their semi-crystalline nature with significant amorphous regions contributes to this toughness.
  3. **High Abrasion Resistance:** One of the most outstanding properties of nylon is its exceptional resistance to abrasion. This makes it highly durable and suitable for applications subject to rubbing and wear, such as carpets, industrial fabrics, and gear components.
  4. **Good Elasticity and Recovery:** Nylons exhibit good elasticity, meaning they can be stretched significantly and then recover to their original shape when the stress is removed. This property is crucial for stretch fabrics, hosiery, and ropes. The elastic recovery is due to the ability of the amorphous regions to uncoil and recoil.

5. **High Fatigue Resistance:** Nylons can withstand repeated cycles of loading and unloading without significant loss of strength or premature failure. This is important for components subjected to dynamic stresses.
6. **Good Flex Life:** They can be repeatedly bent or folded without breaking, making them suitable for applications like conveyor belts and ropes.
7. **Moderate Modulus (Stiffness):** While strong, nylons are not as stiff as some other high-performance fibres (e.g., carbon fibre). Their modulus is moderate, contributing to their flexibility and ability to absorb impact. The modulus can be increased through higher drawing ratios.
8. **Moisture Sensitivity (Property Variation with Water):** Nylons are hygroscopic, meaning they absorb moisture from the atmosphere. Water acts as a plasticizer, reducing hydrogen bonding between chains. This leads to a decrease in tensile strength and modulus, and an increase in elongation and toughness, when wet. This is an important consideration for applications in humid environments.
9. **Creep Resistance:** Nylons generally have good creep resistance, meaning they resist deformation under prolonged stress, though this can be affected by temperature and moisture content.

b) Give detailed classification of fibres.

- **Classification of Fibres:** Fibres can be classified in various ways, primarily based on their origin, chemical composition, or end-use. The most common and fundamental classification is by origin:

#### **I. Natural Fibres:**

- Fibres derived directly from natural sources (plants, animals, or minerals) without significant chemical modification.

- **A. Vegetable (Cellulosic) Fibres:**

- Composed primarily of cellulose.

- **Seed Hairs:**

- Cotton (most important textile fibre)
- Kapok
- Coir (from coconut husk)

- **Bast Fibres (from plant stems):**

- Linen/Flax
- Jute
- Hemp
- Ramie
- Kenaf

- **Leaf Fibres (from plant leaves):**

- Sisal
- Abaca (Manila hemp)
- Pineapple fibre

- **B. Animal (Protein) Fibres:**

- Composed primarily of proteins.

- **Hair/Wool Fibres:**

- Sheep Wool (most common)
- Cashmere (goat)
- Mohair (goat)
- Alpaca (llama family)



- Camel hair
- Angora (rabbit)
- Vicuna, Llama, Guanaco
- **Secreted Fibres:**
  - Silk (from silkworms)
- **C. Mineral Fibres:**
  - Fibres derived from naturally occurring minerals.
  - Asbestos (historically used, but now largely banned due to health hazards)

## **II. Man-Made (Manufactured) Fibres:**

- Fibres produced by humans using chemical processes. They are further categorized into regenerated and synthetic.
- **A. Regenerated (Cellulosic/Protein) Fibres:**
  - Made from natural polymers (cellulose, protein) that are chemically processed, dissolved, and then regenerated into fibre form. The chemical composition is essentially the same as the natural polymer, but the physical structure is modified.
  - **Regenerated Cellulose Fibres:**
    - **Viscose Rayon:** Most common type of rayon.
    - **Modal:** High wet modulus (HWM) rayon, enhanced properties.
    - **Lyocell (Tencel):** Produced by a more environmentally friendly solvent-spinning process.
    - Cuprammonium Rayon (Bemberg)

- **Regenerated Protein Fibres (less common now):**
  - Casein Fibres (e.g., Aralac, Lanital - from milk protein)
  - Zein Fibres (from corn protein)
  - Soy Fibres
- **Other Regenerated Fibres:**
  - Alginate Fibres (from seaweed, often used for medical applications)
- **B. Synthetic Fibres:**
  - Produced from synthetic polymers synthesized from chemical monomers (petroleum-based). These polymers do not exist in nature.
  - **Polyester Fibres:**
    - Polyethylene Terephthalate (PET - most common)
    - Polytrimethylene Terephthalate (PTT)
    - Polybutylene Terephthalate (PBT)
  - **Polyamide Fibres (Nylon):**
    - Nylon 6,6
    - Nylon 6
    - Nylon 6,10, Nylon 11, Nylon 12 (specialty nylons)
  - **Acrylic Fibres:**
    - Polyacrylonitrile (PAN) and its copolymers (e.g., Modacrylics, containing halogenated monomers for flame resistance)
  - **Polyolefin Fibres:**

- Polypropylene (PP)
- Polyethylene (PE)
- **Spandex (Elastane) Fibres:**
  - Polyurethane-based elastic fibres (e.g., Lycra)
- **Aramid Fibres (High Performance):**
  - Para-aramids (e.g., Kevlar - high strength, high modulus)
  - Meta-aramids (e.g., Nomex - high heat and flame resistance)
- **Carbon Fibres:**
  - PAN-based (most common)
  - Pitch-based
  - Rayon-based (less common now)
- **High Performance/Specialty Fibres:**
  - Polybenzimidazole (PBI) - excellent thermal stability, non-flammable
  - Polyphenylene Sulfide (PPS) - chemical and thermal resistance
  - Poly(p-phenylene benzobisoxazole) (PBO) / Zylon - extremely high strength and modulus
  - Ultra-High Molecular Weight Polyethylene (UHMWPE) / Gel-spun PE (e.g., Dyneema, Spectra) - very high strength, low density
  - Ceramic Fibres (e.g., Alumina, Silica)
  - Basalt Fibres

- **Other Synthetic Fibres:**

- Vinyl Fibres (e.g., PVC, PVA)
- Fluorocarbon Fibres (e.g., PTFE/Teflon)

c) Discuss gross structure of wool.

- **Gross Structure of Wool Fibre:**

- Wool fibre, derived from the fleece of sheep, has a complex and unique gross (macroscopic) and microscopic structure that contributes to its characteristic properties such as warmth, resilience, and felting ability.

- **Macroscopic Features (Gross Structure):**

1. **Crimp:** This is the most distinguishing macroscopic feature of wool. Wool fibres are not straight but possess a natural, three-dimensional wavy crimp or curl. The number of crimps per inch varies with the fineness of the wool (finer wools have more crimps).
  - **Significance:** Crimp imparts bulk, resilience, and elasticity to wool fabrics. It traps a large amount of still air, providing excellent insulation. It also contributes to the cohesiveness of wool fibres during spinning, giving yarn strength and preventing slippage.
2. **Length:** Wool fibre length varies significantly depending on the sheep breed, body part, and shearing frequency (e.g., from a few centimeters to over 30 cm). Shorter fibres are typically used for woollen yarns, while longer, finer fibres are used for worsted yarns.
3. **Fineness (Diameter):** This refers to the diameter of the individual wool fibre, measured in microns. Fineness is a crucial determinant of wool quality and end-use. Finer wools

(e.g., Merino) are softer and used for apparel, while coarser wools are used for carpets and industrial textiles.

4. **Colour:** Natural wool colours range from white to various shades of brown, black, and grey. White wool is preferred for dyeing.
5. **Luster:** The natural sheen or lack thereof. Finer wools tend to have a softer, more subdued lustre.

○ **Microscopic Features (Internal Structure - relevant to gross properties):**

1. **Cuticle (Epicuticle, Exocuticle, Endocuticle):** The outermost layer of the wool fibre, composed of overlapping, flattened, scale-like cells (epithelial cells) that point towards the fibre tip.

- **Significance:** These scales contribute to the characteristic "felting" ability of wool (scales interlock under heat, moisture, and mechanical action). They also contribute to the scaly feel and give wool its unique surface properties, influencing lustre and directional friction. The epicuticle is hydrophobic.

2. **Cortex:** The main body of the wool fibre, comprising about 90% of its weight. It consists of millions of spindle-shaped cortical cells aligned parallel to the fibre axis.

- **Bilateral Structure:** In most wool fibres, the cortex is composed of two distinct types of cortical cells: the **orthocortex** and the **paracortex**. These two regions grow at different rates and have different chemical compositions (orthocortex is more absorbent and less crystalline, paracortex is denser and more crystalline).
- **Significance:** The differential swelling and contraction of the ortho- and paracortex is the primary cause of the natural crimp in wool. The cortical cells contain keratin

proteins, which are responsible for wool's strength, elasticity, and resilience.

3. **Medulla (Optional):** A central, honeycomb-like, air-filled core found in coarser wool fibres. It may be continuous, interrupted, or absent in fine wools.

- **Significance:** The medulla can reduce fibre strength and uniform dye absorption in coarser wools. It contributes to insulation by trapping air but can make the fibre feel harsher.

Q.5.a) What is fineness of fibre? Illustrate direct weighing method for its determination.

- **What is Fineness of Fibre?**

- Fineness of a fibre refers to its linear density or its diameter. It is a measure of the mass per unit length or the thickness of an individual fibre. A finer fibre is thinner and typically has a softer handle, better drape, and is used for more luxurious or delicate fabrics. Coarser fibres are thicker and generally more durable and stiff.
- **Units of Fineness:**
  - **Denier (Td):** Mass in grams per 9,000 meters of fibre. Common for man-made fibres.
  - **Tex (Tt):** Mass in grams per 1,000 meters of fibre. An international standard unit.
  - **Decitex (dtex):** Mass in grams per 10,000 meters of fibre.
  - **Micron ( $\mu\text{m}$ ):** Actual diameter in micrometers (for natural fibres like wool and cotton).
  - **Milli-Tex (mtex):** Mass in milligrams per 1,000 meters of fibre.

- **Counts (e.g., NeC, Nm):** Indirect measures, often related to the number of hanks of a certain length per unit weight.
- **Direct Weighing Method for its Determination (e.g., for Denier or Tex):**
  - The direct weighing method is a fundamental principle for determining linear density and is based on the definition of denier or tex. It involves measuring the weight of a precisely known length of fibre.
  - **Principle:** The method relies on the formula: Linear Density (Tex) = (Mass of fibre in grams / Length of fibre in meters) \* 1000  
Linear Density (Denier) = (Mass of fibre in grams / Length of fibre in meters) \* 9000
  - **Procedure:**
    1. **Sample Preparation:**
      - Obtain a representative sample of the fibres to be tested. Ensure the fibres are conditioned to standard atmospheric conditions (e.g., 65% RH, 20°C) to prevent moisture variations from affecting the weight.
      - For continuous filaments, take a long, unbroken length.
      - For staple fibres, individual fibres need to be carefully selected, often using an array technique or by hand picking, ensuring they are free from kinks or damage.
    2. **Length Measurement:**
      - Cut a precise, predetermined length of the fibre. This is critical for accuracy.
      - For example, if determining denier, one might cut exactly 9 meters or 90 meters or 900 meters of fibre. If determining tex, 1 meter or 10 meters of fibre.

- This is often done using a specialized wrap reel or by carefully measuring against a scale. For very short or fine fibres, an even longer length might be amassed to get a measurable weight.

### 3. Weighing:

- Carefully collect the precisely measured length(s) of fibre.
- Weigh the collected fibre using a highly sensitive analytical balance, capable of measuring to at least 0.0001 grams (0.1 mg). The accuracy of the balance is paramount because the weight of a single fibre, even over several meters, is very small.

### 4. Calculations:

- Using the measured weight and the known length, calculate the linear density using the appropriate formula for denier or tex.
- Example for Denier: If 90 meters of fibre weighs 0.009 grams, then:  $\text{Denier} = (0.009 \text{ g} / 90 \text{ m}) * 9000 = 0.0001 * 9000 = 0.9 \text{ Denier}$

### 5. Replication:

- Repeat the process multiple times (e.g., 10 to 50 individual measurements, depending on the fibre type and required precision) from different parts of the sample.
- Calculate the average value to obtain a reliable measurement of the fibre's fineness, as there can be variations within a sample.

#### ○ Limitations:



- Extremely tedious and time-consuming, especially for staple fibres.
- Requires very precise length measurement and highly sensitive weighing equipment.
- Difficult for very fine or short fibres where handling individual fibres is challenging.
- More practical for continuous filament yarns or bundles of fibres where a significant length can be obtained.

b) Discuss physical properties of cotton fibres.

- **Physical Properties of Cotton Fibres:**

- Cotton is a natural cellulosic fibre, derived from the seed hair of the cotton plant. Its unique physical properties make it one of the most widely used textile fibres.
- **1. Length:**
  - Varies significantly depending on the cotton variety (e.g., short staple, medium staple, long staple).
  - Longer staple lengths (e.g., Pima, Egyptian cotton) generally indicate finer, stronger, and more lustrous fibres, yielding smoother and stronger yarns.
- **2. Fineness (Micronaire):**
  - Refers to the fibre's linear density or diameter.
  - Measured in microns, but more commonly expressed by **Micronaire value**, which is a measure of air permeability and correlates with both fineness and maturity of the fibre.
  - Finer cottons (lower micronaire) are used for finer yarns and fabrics.
- **3. Strength (Tenacity):**

- Possesses good dry tensile strength (typically 3.0-5.0 g/den).
- **Unique Property:** Cotton remarkably **gains strength when wet** (typically 10-20% increase). This makes it excellent for washing and allows for mercerization.
- Strength comes from the highly oriented crystalline regions and extensive hydrogen bonding.
- **4. Elongation at Break:**
  - Relatively low (typically 5-10%). This means cotton fabrics don't stretch much and can wrinkle easily, but they also hold their shape well.
- **5. Modulus:**
  - Relatively high, indicating that cotton is quite stiff and resistant to deformation under stress.
- **6. Resilience (Wrinkle Recovery):**
  - Poor resilience and wrinkle recovery. Due to its rigid crystalline structure and low elongation, cotton fabrics tend to wrinkle easily and stay wrinkled unless finished or blended.
- **7. Absorbency (Moisture Regain):**
  - Excellent absorbency and high moisture regain (typically 8.5% at standard conditions).
  - This makes cotton comfortable to wear, as it can absorb perspiration and allow it to evaporate, keeping the wearer cool. It also contributes to its good dyeability.
- **8. Density:**
  - Approximately 1.52 g/cm<sup>3</sup>. This makes it denser than many synthetic fibres.
- **9. Lustre:**

- Naturally has a soft, subdued lustre. Can be enhanced by mercerization.
- **10. Hand (Feel):**
  - Soft, comfortable, and pleasant against the skin.
- **11. Dimensional Stability:**
  - Generally good, but prone to shrinkage if not properly finished or pre-shrunk, especially due to swelling and reorientation of fibres during wet processing.
- **12. Thermal Properties:**
  - Good heat conductor (makes it cool to wear).
  - Degrades at high temperatures, chars rather than melts (around 150°C it begins to degrade, chars around 250-300°C).
  - Flammable.
- **13. Electrical Properties:**
  - Poor electrical conductor, which can lead to static electricity build-up in very dry conditions, although less so than hydrophobic synthetic fibres.
- **14. Resistance to Organisms:**
  - Susceptible to mildew and bacterial degradation, especially in damp conditions, and can be attacked by silverfish and other insects.

c) Describe the key steps involved in the manufacturing process of Basalt fibres and discuss how the processing parameters can influence the properties of the final fibres.

- **Key Steps Involved in the Manufacturing Process of Basalt Fibres:**
  - Basalt fibres are inorganic fibres made entirely from basalt rock, a common volcanic rock. The manufacturing process is a direct melt

process, similar to glass fibre production but with some key differences.

○ **1. Raw Material Selection and Preparation:**

- **Selection:** High-quality, naturally occurring basalt rock, free from impurities and with a consistent chemical composition (especially low content of iron oxides and sulfur, as these can affect fibre properties and processability). Basalt rock is a complex silicate mineral.
- **Preparation:** The basalt rock is crushed into a gravel or chip-like form and then thoroughly cleaned to remove any soil or organic matter.

○ **2. Melting:**

- The basalt chips are fed into a high-temperature furnace (typically gas-fired or electric, sometimes a combination).
- The rock is melted at extremely high temperatures, ranging from 1350°C to 1500°C (or even higher, up to 1600°C), depending on the basalt composition and desired fibre properties. Unlike glass, no additives are mixed; the fibre composition is solely from the rock.
- The molten basalt forms a homogeneous, viscous liquid.

○ **3. Fibre Formation (Drawing/Filamentization):**

- The molten basalt flows from the furnace into a heated platinum-rhodium alloy bushing (a crucible with a large number of precisely drilled nozzles or orifices).
- Continuous filaments are drawn rapidly from these nozzles at high speeds (up to several thousand meters per minute) by a winding drum or puller.

- The rapid drawing and subsequent cooling in air (or sometimes with controlled air quenching) attenuate the molten streams into fine, continuous filaments. The cooling rate is critical.
- **4. Sizing/Coating:**
  - Immediately after drawing, while still hot, a sizing agent (chemical coating) is applied to the individual basalt filaments.
  - **Purpose of Sizing:**
    - Protects the delicate fibres from abrasion during processing and handling.
    - Bundles the individual filaments into strands.
    - Improves wettability and adhesion of the basalt fibres to various matrix materials (e.g., resins in composites, cement in concrete) in downstream applications.
    - Prevents fibre-to-fibre abrasion.
- **5. Drying and Winding:**
  - The sized strands are then dried to remove moisture from the sizing agent.
  - Finally, the continuous strands are wound onto bobbins or spools, or chopped into staple fibres, depending on the intended application.
- **How Processing Parameters Can Influence the Properties of the Final Fibres:**
  - **1. Basalt Rock Composition:**
    - **Influence:** Directly affects the chemical composition of the fibre, which in turn dictates its melting point, viscosity, chemical resistance, and mechanical properties. Variations in silica, alumina, iron oxides, and alkali content can significantly alter fibre strength, modulus, and thermal stability. For

example, higher iron oxide content can increase density and affect colour, while proper alkali content helps control viscosity for spinning.

○ **2. Melting Temperature:**

- **Influence:** Affects the viscosity of the molten basalt and the uniformity of the melt. Higher temperatures generally lead to lower viscosity, which can facilitate drawing finer fibres but also increases energy consumption and can lead to equipment wear. It also influences the thermal history of the material, impacting subsequent crystallization (devitrification).

○ **3. Drawing Speed (Attenuation Rate):**

- **Influence:** A higher drawing speed leads to finer fibre diameters and higher tensile strength due to greater molecular alignment (though basalt is amorphous, the rapid cooling and drawing locks in stress-induced orientation). However, excessively high speeds can lead to fibre breakage. It also influences the cooling rate.

○ **4. Bushing Temperature and Design:**

- **Influence:** Controls the temperature of the molten basalt just before fibre formation, affecting its viscosity at the point of drawing. The number and diameter of the orifices in the bushing determine the number of filaments and influence their fineness.

○ **5. Cooling Rate:**

- **Influence:** Basalt fibres are essentially an amorphous glass. The rapid cooling rate is essential to prevent crystallization (devitrification) within the fibre, which would make it brittle and significantly reduce its strength and flexibility. A controlled cooling rate is crucial for fibre integrity and performance.

○ **6. Sizing Agent Composition:**

- **Influence:** The type of sizing agent is critical for the fibre's compatibility with different matrix materials (e.g., epoxy, polyester, vinyl ester resins, concrete). Proper sizing enhances interfacial adhesion, which is paramount for the mechanical properties of basalt fibre composites (e.g., flexural strength, interlaminar shear strength) and affects handling properties like strand integrity and abrasion resistance.
- **7. Fibre Diameter (Fineness):**
  - **Influence:** Finer fibres generally exhibit higher tensile strength (due to fewer internal defects and more rapid cooling) and provide a greater surface area for adhesion in composites. Coarser fibres are more economical but might offer lower specific strength. This is largely controlled by drawing speed and bushing orifice size.

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