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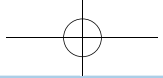
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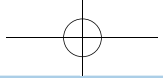
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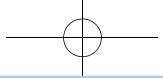
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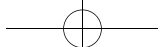
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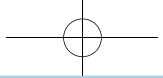
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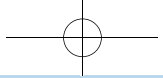
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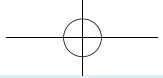


第 1 章

纤维改变生活—— 无处不在的应用

Chapter 1

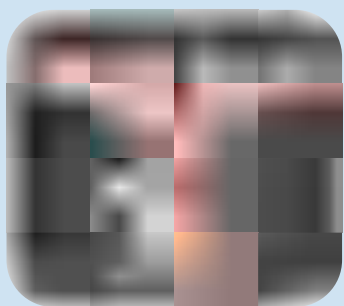
Fibers Change Lives— Ubiquitous Applications



纤维织就美好生活。从缝制衣物的布料，到服务于衣、食、住、行、医及尖端装备等领域的先进基础材料，纤维材料的影子随处可见。

1.1 衣

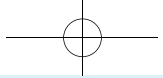
纺织纤维是制作衣物的主要原材料。譬如，大家喜欢的汉服，其渊源可追溯至三皇五帝时期。黄帝“垂衣裳而治天下”，开启了汉服文化的源头，历经周朝的制式演化，到汉朝趋于完善并普及。



1972年，长沙马王堆一号汉墓出土**曲裾式素纱单衣**，这是西汉时期的丝织衣物，由未经染色的三眠蚕丝纱制成；衣长**160厘米**，重量仅为**49克**，有“薄如蝉翼、轻若云雾”的美誉，是存世年代最早、最轻薄的服装珍品，彰显了西汉时期中国丝织技艺的世界领先地位。

时光流转到现代，纤维材料的应用已拓展至太空，化身守护宇航员的“生命屏障”。一件舱外宇航服便是一座微型“纤维科技博物馆”：**外层“金钟罩”**——最外三层使用坚韧的芳纶材料，抵御微流星体撞击，保护宇航员；**躯干“钢筋铁骨”**——上肢躯干部分由玻璃纤维增强的复合材料制成，为宇航服提供支撑；**贴身“空调服”**——最内三层的冷却通风服由氨纶制成，帮助冷水循环，起降温作用。





Fibers weave a better life. From the fabrics used in sewing clothes to the advanced fundamental materials that underpin sectors such as clothing, food, housing, transportation, medicine and cutting-edge equipment, fiber materials are ubiquitous.

1.1 Clothing

Textile fibers serve as the primary raw materials for clothing production. For instance, the traditional Chinese Hanfu, favored by many people today, can be traced back to the era of the Three Sovereigns and Five Emperors. Since the Yellow Emperor “regulated the world by instituting proper clothing and attire,” the prototype of traditional Chinese attire began to emerge. It then underwent institutional evolution during the Zhou Dynasty and eventually became well-developed and widely popularized by the Han Dynasty.

In 1972, the plain unlined gauze gown unearthed from the Han Tomb No. 1 at Mawangdui in Changsha is a silk garment dating to the Western Han Dynasty. It was woven from undyed silk yarn produced by three-molter silkworms. With a length of 160 centimeters and weight of 49 grams, the gown is praised as ‘thin as a cicada’s wing and as light as mist and clouds.’ As the earliest and lightest surviving garment treasure, it showcases the world-leading silk-weaving craftsmanship of China during the Western Han Dynasty.

With the passage of time into the modern era, the application of fiber materials has expanded into outer space, where they transform into a “life barrier” for safeguarding astronauts. Indeed, an extravehicular spacesuit is like a miniature “museum of fiber technology”. The outer “invincible shield”—the outermost three layers are made of aramid fiber materials, designed to withstand micrometeoroid impacts and protect astronauts. The torso’s “steel-like framework”—the upper body and limb sections are constructed from glass fiber—reinforced composites, providing essential structural support for the spacesuit. The “climate-control garment” closest to the body—the innermost three layers of the cooling and ventilation garment are made from spandex fibers, designed to provide effective temperature regulation by helping circulate cold water.



1.2 食

在食品包装行业，不可降解塑料易造成“白色污染”，同时影响食品的品质和安全。那么，有没有一种包装材料可以规避塑料包装的弊端呢？纤维基材料可作为食品包装的“绿色新选择”。

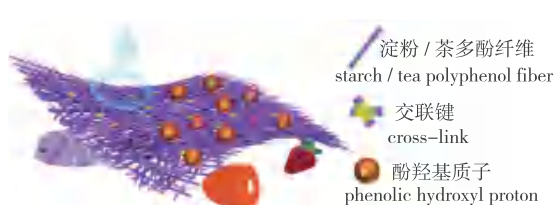
可降解包装

用淀粉制作的**纤维素基膜材料**，具有优异的生物降解性、力学性能和氧气、水汽阻隔性能，可用于食品包装。竹纤维、甘蔗渣纤维能制成可降解餐盒，通过食品安全认证的聚乳酸纤维可做成食品用纸，如茶包、咖啡过滤纸等。



生物活性包装

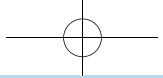
纳米或微米级纤维膜材料具有更高的比表面积、孔隙率和负载率，通过包封生物活性物质（如抗氧化剂和抗菌剂等），可制成多功能纳米纤维膜，能有效延长食品的保质期。



分离与纯化

活性炭纤维可用于油脂脱色，纤维素滤膜在酿酒、制糖行业可用于杂质去除。

作为食品接触材料如包装纸、餐具、薄膜等，需严格限定纤维材料来源，即必须是食品级或允许用于食品接触的原料，并符合食品接触用纤维材料标准。



1.2 Food

In the food packaging industry, non-biodegradable plastics are prone to causing “white pollution” and may also compromise the quality and safety of food. Is there any new type of packaging material that can avoid the drawbacks of plastic packaging? Fiber-based materials offer a promising ‘green alternative’ for food packaging.

Biodegradable packaging

Cellulose-based films prepared from starch exhibit biodegradability, favorable mechanical properties, and excellent barrier performance against oxygen and water vapor, making them suitable for food packaging applications. Bamboo fiber and bagasse fiber can be used to produce biodegradable food containers. Polylactic acid fiber that has passed food safety certification can be used to make food-grade paper, such as tea bags, coffee filter paper and more.



Bioactive packaging

Nano-scale or micron-scale fiber membrane materials possess higher specific surface area, porosity, and loading capacity, enabling them to encapsulate bioactive substances (such as antioxidants and antimicrobial agents) to produce multifunctional nanofiber membranes, which can effectively extend the shelf life of food products.

Separation and purification

Activated carbon fibers can be used for the decolorization of oils and fats. Cellulose filtration membranes can be used for impurity removal in industries such as brewing and sugar production.

As food contact materials such as packaging paper, tableware, and films, the fiber-based materials must be strictly limited to food-grade or approved raw materials for food contact, and comply with the standards for fiber materials intended for food contact use.

1.3 住

说起纤维材料在日常居住空间的应用，大家首先想到的是被子、窗帘等家纺产品，但其实它早已深度融入建筑材料，让房子更坚固，住得更舒适。

建筑结构加固的“隐形钢筋”

在混凝土中加入碳纤维、玻璃纤维等材料，如同给混凝土加了“筋骨”，可提高其坚韧性和抗震性，减少开裂。对于老旧房屋或柱子，用碳纤维布像贴“膏药”一样进行粘贴加固，可显著提高其承载能力。



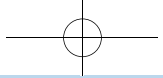
外墙保温抗裂的“黑科技”

岩棉、玻璃棉等无机纤维制品是 A 级防火保温材料，可用于建筑外墙和屋顶，隔热效果特别好，可使室内冬暖夏凉。玻璃纤维机织物经涂覆高分子乳液和高温处理后，制成玻璃纤维网格布，可广泛用作建筑物墙体的保温、抗裂材料等。

高性能纤维增强复合建筑材料

在建筑用防水卷材中加入聚酯纤维、玻璃纤维等材料，防水层不易被撕裂，防水效果更持久。高性能纤维增强复合材料制作的门窗框、装饰板等比传统材料更轻、更耐用。





1.3 Housing

When it comes to the application of fiber materials in everyday living spaces, most people first think of home textile products like quilts and curtains. However, fiber materials have long been deeply integrated into building materials, making houses stronger and living environments more comfortable.

The “invisible steel bars” for building structure reinforcement

Incorporating materials such as carbon fibers and glass fibers into concrete is like giving the concrete “sinew and bone”, which can enhance its toughness and seismic resistance while reducing cracking. For aging buildings or structural columns, applying carbon fiber fabric like a “plaster” for reinforcement can significantly improve their load-bearing capacity.



The “black technology” for exterior wall insulation and crack resistance

Inorganic fiber products such as **rock wool and glass wool** are Class A fire-resistant and thermal insulation materials. They are widely used in building exterior walls and roofs due to their excellent heat insulation performance, keeping interiors warm in winter and cool in summer. After being coated with polymer emulsion and subjected to high-temperature treatment, glass fiber woven fabric is made into glass fiber mesh cloth, which is widely used as a material for thermal insulation and crack resistance in building walls.

High-performance fiber-reinforced composite building materials



Incorporating materials such as polyester fiber and glass fiber into waterproofing membranes for construction, the waterproof layer becomes more tear-resistant and provides longer-lasting protection. High-performance fiber-reinforced composite materials used in the production of door and window frames, decorative panels, and other components are also exceptionally outstanding, being lighter and more durable than traditional materials.

1.4 行

纤维材料在现代出行与交通运输领域也发挥着巨大作用，纤维增强复合材料更是让汽车、高铁、飞机等交通工具实现轻量化、绿色化的关键推手。

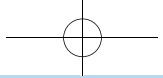


轮胎帘子线是轮胎骨架增强材料，常用锦纶、涤纶、对位芳纶等纤维。帘布层通常由多层浸胶帘线以橡胶黏合而成，起着提高轮胎强度和稳定外胎的作用。用高强锦纶织物制成的安全气囊，由涤纶长丝制成的安全织带，协同阻燃纤维内饰，共同守护乘客安全。

碳纤维、玻璃纤维的复合材料用于制造汽车的部分零部件，如车身、底盘、电池壳、引擎盖等，可使汽车减重，节省燃油。

纤维增强复合材料用于制作高铁的流线型车头罩，可减重降噪，并保障高速运行时的结构稳定。碳纤维复合材料代替飞机的部分铝合金，可**实现减重增强**。如波音 787 的机身、机翼等采用碳纤维复合材料的占比超过 50%，可降低燃油消耗，减少基于飞机重量的维修费用和定检次数。





1.4 Transportation

Fiber materials also play a significant role in the field of modern transportation. Fiber-reinforced composites have become a key driver in making vehicles such as cars, high-speed trains, and airplanes lighter and more environmentally friendly.

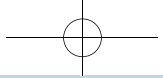
The tire cord is the skeletal reinforcement material of tires, commonly made from fibers such as nylon, polyester, and para-aramid. The tire cord layer is usually formed by bonding multiple layers of dipped cord with rubber, which serves to enhance the tire's strength and stabilize the outer tire structure. The airbag made from high-strength nylon fabrics and the safety belt woven from polyester filaments, in cooperation with flame-retardant fiber interiors to jointly ensure passenger safety. *Composites made from carbon fiber and glass fiber* are used to manufacture some automotive components, such as the body, chassis, battery shell, and engine hood. They can reduce vehicle weight and cut fuel consumption.



The fiber-reinforced composites are used to manufacture the streamlined nose cones of high-speed trains, to reduce weight and noise while ensuring structural stability at high speeds. Replacing certain aluminum alloy components in aircraft with carbon fiber



composites can achieve *weight reduction and strength enhancement*. For instance, in the Boeing 787, carbon fiber composites account for more than 50% of the aircraft's fuselage and wings, significantly reducing fuel consumption, lowering weight-based maintenance costs and decreasing the frequency of scheduled inspections.



1.5 医

纤维材料在医疗领域也是“隐藏高手”，因其柔软、安全、可降解，被广泛用于诊疗、护理和康复领域。

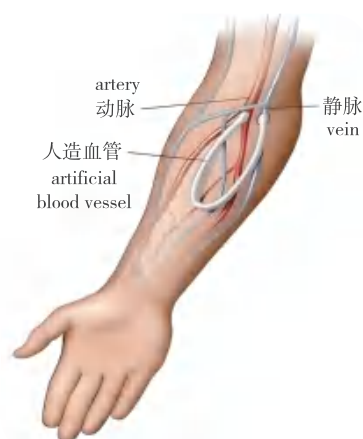
医用纤维制品所用原料包含天然纤维（如棉纤维、蚕丝）、再生纤维素纤维（如壳聚糖纤维、海藻纤维）、合成纤维（如聚酯纤维、聚酰胺纤维）和其他纤维（如碳纤维、玻璃纤维）。常见的医用纤维制品可分为医用辅料、医用缝合材料、人体组织器官代用材料和器械组件等。

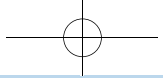
医用辅料包括脱脂棉、脱脂纱布、止血海绵等**吸水性辅料**，口罩、手术衣、手术盖巾、病床用品等**保护性辅料**，绷带、氧化锌橡皮膏等**支持固定性辅料**。



医用缝合材料主要指手术缝合线，如用聚乳酸纤维制成的可吸收缝合线，能被人体分解、吸收，无须拆线，可减少病人的痛苦和感染风险。

人体组织器官代用材料帮助“修复”身体，常见的有人造血管、疝气补片、心脏瓣膜、中空纤维人工肾等。用聚酯纤维或膨体聚四氟乙烯纤维制成的人造血管，既能保证血液畅通，又可避免人体的排异反应。





1.5 Medicine

Fiber materials also play an “understated yet crucial role” in the medical field. Being soft, safe and biodegradable, they are widely employed in disease treatment, nursing care and rehabilitation.



The raw materials for medical fiber products include natural fibers (e.g., cotton fiber, silk), regenerated cellulose fibers (e.g., chitosan fiber, alginate fiber), synthetic fibers (e.g., polyester, polyamide) and other types of fibers (e.g., carbon fiber, glass fiber). Common medical fiber products can be classified into medical dressings, medical suturing materials, human tissue substitutes and medical device components, etc.

Medical dressings include **water-absorbent materials** such as absorbent cotton, gauze and hemostatic sponges; **protective materials** such as face masks, surgical gowns, surgical drapes and bed linen; as well as **supporting and fixation materials** like bandages and zinc oxide adhesive plasters.



Medical suturing materials mainly refer to surgical sutures. The absorbable sutures made from polylactic acid fibers can be decomposed and absorbed by the human body, eliminating the need for suture removal and thereby reducing patient discomfort and the risk of infection.



Human tissue substitutes assist in the “repair” of the body. Typical applications include artificial blood vessels, hernia repair patches, heart valves, and hollow-fiber artificial kidneys. Artificial blood vessels fabricated from polyester fibers or expanded polytetrafluoroethylene fibers can not only ensure unobstructed blood flow but also help avoid adverse immune reactions in the human body.

1.6 航空航天

你有没有想过，我们日常穿着的衣服面料，直接置于太空环境会怎样？答案是：纤维材料快速劣化。那宇航员和航天器如何在太空中安然无恙呢？这离不开材料界的“特种兵”——高性能纤维。

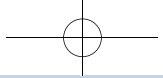


2020年12月3日，嫦娥五号探测器在月球表面首次成功展开“**织物版**”国旗，国旗面料以**国产高性能芳纶**为主，可从容应对月球表面的极端温差（ $\pm 150^{\circ}\text{C}$ ），保持颜色和结构稳定。2024年6月4日，嫦娥六号探测器上成功展开“**石头版**”国旗，选材以**玄武岩纤维**为主，可有效耐受月面

的高低温交变、高真空及强紫外线辐射等恶劣环境。

纤维材料还可以编织成三维立体结构织物。**三维编织复合材料**具有重量轻、强度高、耐损伤等优异特性，用于飞机的机身、机翼等关键部件，能显著提升飞机的综合性能，并减少燃料消耗。火箭整流罩和国产“歼-10C”战斗机的雷达罩等都离不开它。高性能纤维及三维编织技术是支撑我们遨游太空、锻造强国重器背后不可或缺的“硬核科技”。

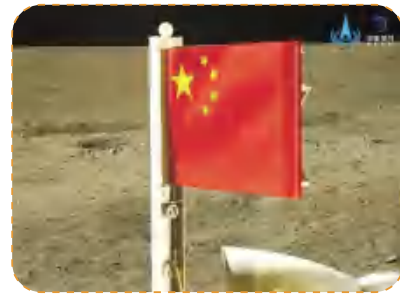




1.6 Aerospace

Have you ever considered what would happen if ordinary clothing fabrics were exposed directly to the space environment? The answer is that the fiber materials would degrade rapidly. Then how do astronauts and spacecraft remain unharmed in the space environment? This relies on the “special forces” in the materials field—high-performance fibers.

On December 3, 2020, the Chang’e-5 probe successfully unfurled the “fabric version” national flag on the lunar surface for the first time. The flag was primarily made of domestically produced high-performance aramid fibers, which can withstand the extreme temperature differences ($\pm 150^{\circ}\text{C}$) on the lunar surface, to maintain



stable color and structure. On June 4, 2024, the “stone-derived fabric” national flag was successfully unfurled on the Chang’e-6 probe. Primarily made of basalt fibers, the flag can effectively withstand harsh lunar environmental conditions such as alternating high and low temperatures, high vacuum, and intense ultraviolet radiation.



Fiber materials can also be fabricated into three-dimensional (3D) structural fabrics. 3D braided composites exhibit excellent properties such as light weight, high strength and superior damage tolerance. When applied to the key aircraft components, such as fuselages and wings, they can significantly enhance the overall performance of aircraft and

reduce fuel consumption. These materials are also indispensable for components such as rocket fairings and the radomes of China’s domestically developed J-10C fighter jets. High-performance fibers and 3D weaving technology stand as the indispensable “hard-core technologies” underpinning our exploration of outer space and the creation of key national strategic equipment.

1.7 土工材料

纤维材料是生态修复、农业增产、基建工程等领域的“多面手”。

土壤和农业

黄麻等纤维制品拥有超强的吸水性（吸水率达480%），能减缓雨水冲刷和灌溉水流的速度，降低土壤侵蚀风险。农用非织造布具有透光透气、保温保湿和易降解等优点，用它代替传统塑料地膜，既可促进作物生长，还能减少“白色污染”。



道路与工程

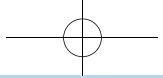
玄武岩纤维加入沥青混合料中，可将路面的抗疲劳开裂能力提高2~6倍，抗车辙能力提高25%~40%。玻璃纤维等用作路面防水层的增强材料，可减少防水层的开裂和渗漏，提高道路的承载能力和使用寿命。

地下管网

水泥管道曾是城市排水系统的“主力军”，但运输、安装难度大，使用寿命短，且不耐腐蚀，污水易渗漏。塑胶管道轻便、耐腐蚀，但其强度和耐热性差强人意。



玄武岩纤维增强聚乙烯复合管道，既轻便耐腐蚀，又格外坚韧，能承受45吨的抗压测试，使用寿命可长达50年！足以托起给水排水重任，确保城市地下的“血脉”畅通。

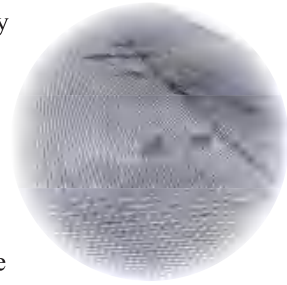


1.7 Geotechnical Materials

Fiber materials serve as “all-rounders” in fields such as ecological restoration, agricultural productivity enhancement and infrastructure engineering.

Soil and agricultural application

Fiber products such as **jute** possess exceptionally high water absorption capacity (reaching **480%**), which can effectively slow down the speed of rainfall-induced runoff and irrigation water flow, thereby reducing the risk of soil erosion. Agricultural non-woven fabrics offer advantages such as light permeability, breathability, thermal insulation, moisture retention and ease of degradation. Their application as a substitute for conventional plastic mulch can not only facilitate crop growth but also reduce “white pollution.”



Road and civil engineering application

The incorporation of **basalt fibers** into asphalt mixtures can enhance the fatigue cracking resistance of pavement by a factor of **2~6**, and improve its rutting resistance by **25%~40%**. Materials such as **glass fiber** are employed as reinforcements in pavement waterproofing systems, which can reduce the cracking and leakage of the waterproof layers, thereby enhancing the load-bearing capacity and service life of roads.

Underground pipe networks

Cement pipes were once the mainstay of urban drainage systems. However, they suffer from great difficulty in transportation and installation, limited service life, poor corrosion resistance, and a high tendency for sewage leakage. Plastic pipes are lightweight and corrosion-resistant, yet they are deficient in strength and heat resistance. **Basalt fiber-reinforced polyethylene composite pipes** not only retain the advantages of light weight and corrosion resistance, but also exhibit exceptional toughness. Capable of withstanding **45 tons** of compressive force and boasting a **50-year** service life, they are more than adequate for critical water supply and drainage tasks, ensuring the unimpeded flow of the city’s underground “lifeblood.”

1.8 海洋及航海

纤维材料在海洋及航海领域同样是“大功臣”，轻便、坚韧、耐腐蚀的特性，让它在海洋工程领域大放异彩。

守护生命的“安全纤维”

锦纶、涤纶、芳纶等纤维材料常被用来制作救生衣、救生筏、救生绳等装备，能在紧急时刻为海上人员提供可靠的安全保障。

深海探测的“生命线”

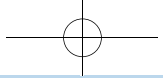
深海油田使用的锚固缆绳和生产井管用**碳纤维材料**部分代替后，可有效降低平台重量，节约成本。例如，一个 1,500 米的深海作业平台，钢制缆绳使用量大约为 **6,500 吨**，换成碳纤维缆绳能减少 **1/6** 的重量。**超高分子量聚乙烯缆绳**强度高、质轻、耐海水腐蚀，是深海作业的“**超级绳子**”，广泛用于大型船舶的系泊。



深海装备的“盔甲”

纤维增强复合材料制造的船体，既轻便又坚固，用于**深海航行器耐压舱**，能使其下潜深度提高 **3~4 倍**。中国自主设计建造的“海翼”号水下滑翔机，其耐压舱使用碳纤维缠绕复合材料。2017 年在马里亚纳海沟成功下潜至 **6,329 米**，刷新了世界水下滑翔机最大潜深的纪录。





1.8 Marine Operations

Fiber materials also serve as “key contributors” in the marine and maritime fields. With their lightweight, high-strength, and corrosion-resistant properties, such materials demonstrate outstanding performance in marine operations.

Life-guarding “safety fibers”

Fibers such as **polyamide**, **polyester** and **aramid** are commonly used to make life jackets, life rafts, lifelines and other equipment, offering reliable safety assurance for maritime personnel in emergency situations.

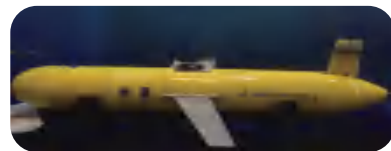
Deep-sea exploration’s vital lifeline

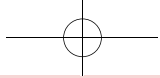
By partially replacing anchor cables and production risers with **carbon fiber materials** in deep-sea oilfields, can effectively reduce platform weight, and generate significant cost savings. For instance, a deep-sea operation platform with a depth of 1,500 meters typically utilizes around **6,500 tons** of steel cables; substituting these with carbon fiber cables can reduce the total weight by **one-sixth**. **Ultra-high molecular weight polyethylene ropes**, characterized by high tensile strength, lightweight, and excellent resistance to seawater corrosion, are the “**super ropes**” of deep-sea operations and are extensively employed in the mooring of large ships.



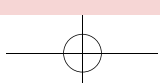
The “armor” of deep-sea equipment

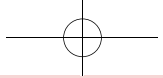
Fiber-reinforced composite hulls exhibit superior lightweight and high-strength properties. When used in the **pressure hulls of deep-sea submersibles**, they can increase the maximum diving depth by **3 to 4 times**. The domestically independently developed “Sea Wing” underwater glider features a pressure hull constructed from carbon fiber-wound composites. In 2017, it successfully dived to **6,329 meters** in the Mariana Trench, setting a new world record for the maximum depth achieved by an underwater glider.





纤维博物馆 FIBER MUSEUM





第2章

纤维与人类文明—— 从古至今的“线”索

Chapter 2

Fibers and Human Civilization— The Thread Connects Our Past and Future



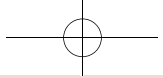
纤维技术的演进史同时也是人类文明进化史的重要组成部分。从遮蔽身体的原始需求，到定义身份的文明符号，再到改造世界的科技媒介，纤维是一种推动人类文明进程的关键材料。

2.1 什么是纤维？

纤维是指具有足够的细度（**直径** < 100 微米）和长径比（**长度** / **直径** > 1,000），满足一定强度要求、可柔性加工的细丝状材料，作为纺织纤维还必须具备可纺性和使用性，纤维可分为天然纤维和化学纤维。

最初用于制作布料的纤维材料源自亚麻、棉花、羊毛和蚕丝等，属于**天然纤维**。1884年，法国人夏尔多内（Hilaire de Chardonnet）发明了硝酸纤维素纤维，并于1891年首次实现该纤维的工业规模生产，标志着人类开始有能力制造**化学纤维**。1935年，锦纶（聚酰胺纤维）的发明，揭开了**合成纤维**的序幕。随后，涤纶、腈纶等合成纤维相继问世，并迅速成为纺织服装领域的主流材料。随着高科技领域的需求升级，碳纤维、超高分子量聚乙烯纤维等**高性能合成纤维**应运而生，进一步拓宽了纤维材料的种类和应用领域。



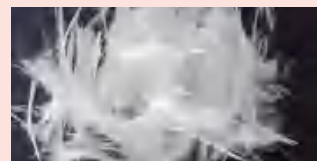


The evolution of fiber technology is also an important part of the history of the advancement of human civilization. From the primitive need to cover the body, to a cultural symbol that defines identity, and then to a technological medium that transforms the world, fiber has been a key material driving the progress of human civilization.

2.1 What is Fiber?

Fiber refers to a fine filamentous material with sufficient fineness ($\text{diameter} < 100 \mu\text{m}$) and a high aspect ratio ($\text{length/diameter} > 1,000$), meeting certain strength requirements and capable of being processed flexibly. To be used as a textile fiber, it must also possess spinnability and serviceability, and can be categorized into natural and chemical fibers.

Initially, the fiber materials used for fabric production were derived from flax, cotton, wool, silk and so on, all of which were **natural fibers**. In 1884, the Frenchman Hilaire de Chardonnet invented nitrocellulose fiber, and he achieved the world's first industrial-scale production of this fibers in 1891, which is a milestone marking humanity's ability to produce **chemical fibers**. The invention of polyamide in 1935 pioneered the history of **synthetic fibers**. Subsequently, common synthetic fibers such as polyester and **acrylic** were introduced one after another, and quickly became the mainstream materials in the field of textile and clothing. With the upgrading of demands in high-tech fields, **high-performance synthetic fibers** such as carbon fiber and ultra-high molecular weight polyethylene (UHMWPE) **fiber** have emerged, further expanding the variety and application scope of fiber materials.



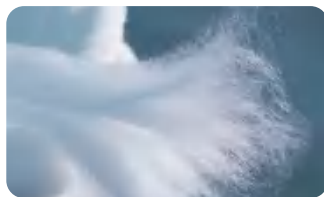
2.2 纤维——人类文明的使者

纤维贯穿生命、文明与科技演进，是连接人类文明的使者。

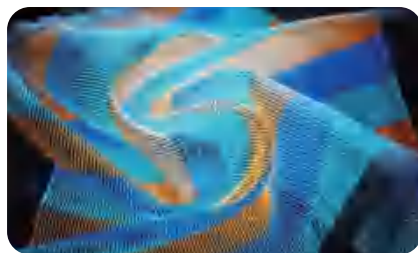
远古时期，人类利用动物皮毛、树皮纤维等天然纤维材料制成最原始的衣物遮体御寒。**农耕文明时期**，中国的丝绸、古埃及的亚麻、印度的棉纺织，均依托纤维材料形成独特的地域文化，纤维成为文化符号与贸易纽带。

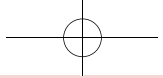


工业革命以来，人类对纤维的利用从“被动获取”转向“主动创造”。先后创制了一系列化学纤维，如满足大规模人口消费需求的黏胶纤维等**再生纤维**和锦纶、涤纶等**合成纤维**，以及支撑现代高新科技发展的碳纤维、芳纶（Kevlar）、聚对亚苯基苯并二噁唑（PBO）纤维等**高性能纤维**。



未来，纤维材料向绿色化、智能化方向发展。聚乳酸纤维等**生物基合成纤维**可减少对石油资源的依赖，**光学纤维**以光速传递着全球的数据洪流，**智能纤维**集成传感器和各种功能材料，能够敏锐感知并响应外界刺激，可被编织成柔性可穿戴纺织品，用于智慧监测、医疗健康等领域。





2.2

Fiber—The Messenger of Human Civilization

Fibers are the key threads running through the evolution of life, civilization and technology, and messengers connecting human civilizations.



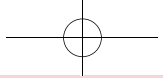
In ancient times, humans made the most primitive clothing from natural fiber materials such as animal hides and bark fibers to cover their bodies and keep warm. During the agricultural civilization era, Chinese silk, ancient Egyptian linen, and Indian cotton textiles all developed unique regional cultures based on their respective fiber materials. Thus, fibers have become cultural symbols and trade links.

Since the Industrial Revolution, humanity's utilization of fibers has shifted from “passive acquisition” to “active creation”. A variety of chemical fibers have been successfully developed, such as regenerated fibers like viscose fibers and common synthetic fibers like nylon and polyester that meet the consumption needs of mass consumption, as well as high-performance fibers like carbon fibers, aramid (Kevlar), and poly-p-phenylene benzobisoxazole (PBO) fibers that underpin the development of modern high and novel technologies.



In the future, fiber materials will move toward greenization and intellectualization. Bio-based synthetic fibers such as polylactic acid fibers can reduce dependence on petroleum resources. Optical fibers transmit global data flow at the speed of light. Intelligent fibers integrated with sensors and various functional materials, can sensitively perceive and respond to external stimuli, they can be woven into flexible wearable textiles and applied in smart monitoring, medical health and other fields.





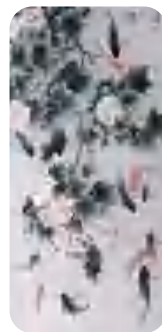
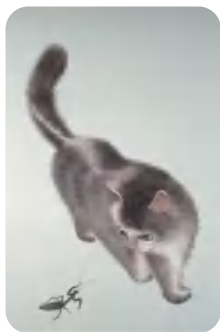
2.3 中国纤维史

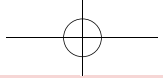
天然纤维的基础应用与繁荣发展

旧石器时代，先民利用野生植物纤维、动物皮毛制作绳索与简易遮蔽物。6,000多年前，我国先民发明了葛布的制作方法；商周时代，葛布成为最重要的制衣材料。秦汉时期，**苎麻布**开始在民间普及，成为主要衣料。元代以后，棉花普及；明清时期，棉布成为最主要的衣料。时至今日，以纤维长、强度高、色泽白享誉全球的新疆棉花，成为制作高档纺织品的绝佳原料。



中国丝绸承载着五千年文明印记，是中华文化瑰宝及东西方文明交流的重要载体。“五星出东方利中国”**汉代蜀锦护臂**被誉为“丝绸之路”上跨越千年的文化纽带。丝织业形成蜀锦、宋锦、云锦、壮锦四大名锦，举世闻名的“四大名绣”，**苏绣、湘绣、粤绣和蜀绣**更是世界级和国家级非物质文化遗产。





2.3 The History of Fibers in China

Basic applications and prosperous development of natural fibers

During the Paleolithic Age, early humans made ropes and simple shelters using wild plant fibers and animal hides. More than 6,000 years ago, early humans in China invented the manufacturing method of kudzu cloth, which had become the most important material for making clothing by the Shang and Zhou dynasties. During the Qin and Han dynasties, **ramie cloth** became popular among the folk and emerged as a primary clothing material. After the Yuan Dynasty, cotton gained popularity, and emerged as the dominant clothing material during the Ming and Qing Dynasties. Up to now, Xinjiang cotton, renowned worldwide for its long fiber length, high strength and pure white color, has become an excellent raw material for manufacturing high-end textiles.

Chinese silk, bearing the imprints of 5,000 years of civilization, is a treasure of Chinese culture and an important carrier for exchanges between Eastern and Western civilizations. The **Han-dynasty Shu brocade arm guard** inscribed with “Five Stars Rise in the East, Benefiting China” is hailed as a millennium-spanning cultural link along the Silk Road. The silk weaving industry gave rise to four famous silk fabrics: Shu brocade, Song brocade, Yun brocade and Zhuang brocade. The world-famous “Four Great Embroideries,” namely **Suzhou Embroidery**, **Hunan Embroidery**, **Cantonese Embroidery** and **Shu Embroidery**, are acclaimed as world-class and national intangible cultural heritage items.



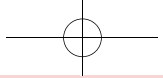
天然纤维到化学纤维的技术革命

天然纤维的力学性能和耐磨性能略差，且生长周期长，无法满足中国近代社会人口快速增长对纤维材料的消费需求，同时，面临着“粮棉争地”矛盾和纺织工业原料供应的困境，中国将发展化学纤维定为重要发展方向。20 世纪 40 年代，辽宁丹东建立黏胶纤维厂，标志着中国现代化学纤维工业化生产起步；1956 年，北京建成中国最早的合成纤维厂，生产锦纶 66 长丝；1974 年，上海石化总厂引进建设了首个大型石油化纤项目，主要生产腈纶、涤纶，开启了以石油为原料的现代合成纤维工业新纪元。改革开放以后，化学纤维工业迅速发展，涤纶品类成为化纤工业的顶梁柱，腈纶、氨纶也开始进行产业化探索。

纤维产业由技术追赶到当代引领的跨越

1998 年，中国的化学纤维产量首次超过美国，跃居世界第一。2000 年以后，中国的化学纤维产业迈入“高端化、绿色化”的新发展阶段。2010 年之后，高性能纤维打破国外技术封锁，碳纤维、**芳纶**、超高分子量聚乙烯纤维等实现自主化生产，服务于航空航天、国防军工、新能源等高精尖领域；大力发展绿色纤维，如生物基纤维（聚乳酸纤维、**海藻纤维**等）、循环再生纤维（利用废旧塑料瓶制成再生涤纶），响应“双碳”目标；积极开发具有智能调温、导电、抗菌、传感等特性的功能性和智能性纤维，赋能智能可穿戴、医疗健康等新兴领域。





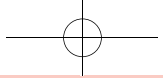
The technological revolution from natural fibers to chemical fibers

The mechanical properties and wear resistance of natural fibers are slightly inferior, coupled with their long growth cycles, which made them unable to meet the demand for fiber materials driven by the rapid population growth in modern Chinese society. Meanwhile, confronted with the conflict of “grain-cotton and competition” and the raw material shortage in the textile industry, China had designated the development of chemical fibers as an important direction. In the 1940s, a viscose fiber factory was established in Dandong, Liaoning Province, marking the launch of the industrialized production of modern chemical fibers in China. In 1956, China’s earliest synthetic fiber factory was built in Beijing, which produced polyamide 66 filaments. In 1974, the Shanghai Petrochemical Complex introduced and constructed China’s first large-scale petrochemical fiber project, which mainly produced acrylic fiber and polyester fiber, thus inaugurating a new era of modern synthetic fiber industry based on petroleum feedstock. After the reform and opening-up, the chemical fiber industry developed rapidly. Polyester emerged as the mainstay of the chemical fiber industry, while acrylic fiber and spandex also embarked on the exploration of industrialization.

The leap of fiber industry from technological catch-up to contemporary leadership

China’s chemical fiber output became the world’s highest for the first time, surpassing the United States in 1998. Since the 2000s, China’s chemical fiber industry has stepped into a new stage of high-end and green development. After 2010, China broke the foreign technological blockade on high-performance fibers. Key materials such as carbon fibers, **aramid**, ultra-high-molecular-weight polyethylene fibers achieved independent production and were applied in high-end and cutting-edge fields including aerospace, national defense, military industry and new energy. Huge efforts are devoted to the development of green fibers, such as bio-based fibers, e.g., polylactic acid fibers and **seaweed-derived fibers**, as well as recycled fibers, e.g., recycled polyester produced from waste plastic bottles, in response to the “dual carbon” goals. Functional and intelligent fibers with properties such as intelligent temperature regulation, electrical conductivity, antibacterial activity, and sensing capabilities are actively developed to empower emerging fields including smart wearables and healthcare.





互动：纤维时间轴



蒙昧时代（5万~10万年前），将草茎和树皮搓捻成绳子，用兽皮和树叶蔽体御寒。

旧石器时代，用骨针缝制兽皮制作原始衣物。

新石器时期，从葛藤中提取植物纤维制作蔽体的衣物，是原始纺织业的发端。

商周时期（公元前1600年—前256年），养蚕缫丝，开启利用动物纤维的新纪元。

汉魏时期，利用擀毡工艺将动物毛发捶打挤压成毛毡。

南宋时期，刺绣得到大发展。

19世纪末至20世纪30年代，人造纤维的起步和创新阶段。

1857年，瑞士化学家施魏策尔（Matthias Eduard Schweizer）发现铜氨溶液能溶解纤维素，德国Bemberg公司在20世纪初成功实现铜氨纤维的商业化生产。

1884年，法国人夏尔多内（Hilaire de Chardonnet）发明硝酸纤维素纤维，并于1891年建立世界首家人造丝工厂，标志化学纤维工业化开端。

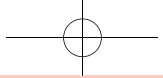
1905年，黏胶纤维实现工业化生产，成为早期主流人造纤维，缓解天然纤维短缺。

20世纪20年代，实现二醋酸纤维的规模化生产。

1932年，美国工程师斯莱特（Russell Games Slayter）首次实现了玻璃纤维的连续抽丝，为大规模工业化生产奠定了基础。

1935年，美国哈佛大学教授卡罗瑟斯（W.H.Carothers）用己二胺和己二酸成功合成锦纶66，并纺成丝条。

1939年，美国杜邦（Du Pont）公司实现了锦纶66的大规模生产，开启合成纤维时代。



1941 年，温菲尔德（John Rex Whinfield）与合作者迪克森（James Tennant Dickson）采用对苯二甲酸与乙二醇进行缩聚，首次合成了高分子量的聚对苯二甲酸乙二醇酯（涤纶）。

1947 年，英国帝国化学工业公司（ICI Industries）购买了温菲尔德和迪克森的专利，并建立了中试工厂，陆续突破了中间体制备、聚合物合成及纺丝等生产技术。

1947 年，英国 ICI 公司采用熔体纺丝技术实现了聚对苯二甲酸乙二醇酯纤维的工业化。

1950 年，美国杜邦公司采用干法纺丝实现了聚丙烯腈纤维“Orlon”的工业化；聚乙烯醇缩醛化纤维（维纶）在日本投入工业化生产。

1957 年，意大利蒙特卡蒂尼联合公司（Montecatini Societa Generale）开始生产等规聚丙烯树脂，1959 年开始生产等规聚丙烯纤维（丙纶）。

1959 年，美国杜邦公司通过干法纺丝实现了聚氨酯甲酸酯弹性纤维（氨纶）“Lycra”的工业化；美国联合碳化物公司推出“Thornel-25”黏胶基碳纤维，成为世界上第一种商品化碳纤维；日本科学家近藤昭男发明聚丙烯腈（PAN）基碳纤维，奠定了现代碳纤维工业的基础。

1967 年，间位芳族聚酰胺纤维（芳纶 1313）由美国杜邦公司实现商业化生产，其商品名为 Nomex。

1972 年，对位芳族聚酰胺纤维（商品名 Kevlar）由美国杜邦公司实现工业化生产。

1975 年，荷兰采用凝胶纺丝法成功制备出超高分子量聚乙烯（UHMWPE）纤维。

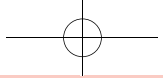
1985 年，乌克兰纤维实验室建成世界首条玄武岩纤维工业化生产线。

1990 年，莱赛尔纤维（Lyocell）产业化，以环保溶剂纺丝技术推动人造纤维绿色升级。

1994 年，日本 Kanebo 与 Shimadzu 公司合作开发纯纺聚乳酸纤维（Lactron™）。

1997 年，美国 Outlast 公司获得 Triangle 公司的相变微胶囊技术专利授权，并开始生产销售含有蓄热调温微胶囊的纤维制品。

2000 年，中国吉林化纤股份有限公司完成竹纤维小试，2002 年实现竹浆批量生产。



2005 年，聚乳酸（PLA）纤维实现规模化量产，成为生物基合成纤维产业化里程碑。

2008 年，威海光威复合材料股份有限公司突破 T300 级碳纤维工程化技术，打破国外技术垄断。

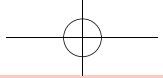
2015 年，中复神鹰碳纤维股份有限公司实现 T800 级碳纤维工程化量产，标志着国产碳纤维进入高端应用领域。

2017 年，中国实现 Lyocell 纤维国产化与规模化生产。

2020 年，全球生物基纤维产量突破 200 万吨，聚乳酸纤维、聚羟基烷酸酯等品种快速增长，生物基纤维成为纤维绿色转型核心力量。

2022 年，中国石化建成国内首条 48K 大丝束碳纤维生产线，成功打破了长期以来的国际技术壁垒与市场垄断。

2025 年，重庆国际复合材料股份有限公司推出模量 100GPa 的超高模玻璃纤维，配套热塑性风电叶片，解决叶片回收难题，助力风力发电产业绿色闭环发展。



Interaction—Fiber Timeline



In the Age of Savagery (50,000~100,000 years ago), early humans twisted straw and tree bark into ropes, and used animal hides and leaves to cover and warm their bodies.

In the Paleolithic Age, primitive humans used bone needles to sew animal hides into rudimentary clothing.

In the Neolithic Age, early humans extracted plant fibers from kudzu vines to make body-covering garments, which marked the origin of primitive textile industry.

During the Shang and Zhou Dynasties (c. 1600–256 BCE), sericulture and silk reeling inaugurated a new era of animal fiber utilization.

During the Han and Wei Dynasties, people produced felt by pounding and pressing animal hair using the felting process.

During the Southern Song Dynasty, embroidery experienced remarkable development.

The late 19th century to the 1930s was the initial and innovative phase of man-made fibers.

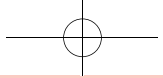
In 1857, Swiss chemist Matthias Eduard Schweizer discovered that cuprammonium solution can dissolve cellulose, and the Bemberg company of Germany successfully commercialized cuprammonium fiber production in the early 20th century.

In 1884, the Frenchman Hilaire de Chardonnet invented nitrocellulose rayon, and in 1891 he established the world's first rayon factory, marking the dawn of the industrialization of chemical fibers.

In 1905, viscose fiber achieved industrialized production, emerging as the mainstream man-made fiber in the early stage and alleviating the shortage of natural fibers.

In the 1920s, the large-scale production of cellulose diacetate fiber was realized.

In 1932, American engineer Russell Games Slayter achieved the world's first continuous



filament drawing of glass fiber, laying the foundation for its large-scale industrial production.

In 1935, Professor W. H. Carothers from Harvard University successfully synthesized polyamide 66 using hexamethylenediamine and adipic acid, and spun it into filaments.

In 1939, DuPont(US) successfully produced the world's first large-scale synthetic fiber for textile, polyamide 66 fiber, ushering in the era of synthetic fibers.

In 1941, John Rex Whinfield and James Tennant Dickson first synthesized high-molecular-weight polyethylene terephthalate (PET, polyester fiber) by polycondensation of terephthalic acid and ethylene glycol.

In 1947, ICI of the UK acquired their patents and built a pilot plant, making breakthroughs in intermediate preparation, polymer synthesis and spinning technologies.

In 1947, Imperial Chemical Industries (ICI) in UK industrialized polyethylene terephthalate (PET) fiber by adopting melt spinning technology.

In 1950, DuPont(US) industrialized the polyacrylonitrile fiber "Orlon" via dry spinning. Polyvinyl alcohol acetal fiber (vinylon) has been put into industrial production in Japan. Polypropylene (PP) fiber has also been industrialized successively. Thus, forming the mainstream synthetic fiber system.

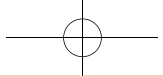
In 1957, Italy's Montecatini Societa Generale began to produce isotactic polypropylene resin, and launched isotactic polypropylene fiber (polypropylene fiber) in 1959.

In 1959, Du Pont(US) industrialized polyurethane elastic fiber "Lycra" through the dry spinning process. Union Carbide Corporation of the United States launched "Thornel-25", a viscose-based carbon fiber, becoming the world's first commercialized carbon fiber. Japanese scientist Akio Kondo invented polyacrylonitrile (PAN)-based carbon fiber, laying the foundation for modern carbon fiber industry.

In 1967, DuPont(US) commercialized meta-aramid fiber (Aramid 1313), with the trade name of Nomex.

In 1972, DuPont(US) achieved the industrial production of para-aramid fiber, with the trade name Kevlar.

In 1975, the gel spinning process was adopted in the Netherlands to successfully produce ultra-high molecular weight polyethylene (UHMWPE) fiber.



In 1985, the first industrial production line for basalt fiber in the world was completed by the Ukrainian Fiber Laboratory.

In 1990, Lyocell fiber was industrialized, and its eco-friendly solvent spinning technology drove the green upgrading of man-made fibers.

In 1994, the Kanebo Corporation and Shimadzu Corporation of Japan jointly developed the 100% spun polylactic acid fiber (Lactron™).

In 1997, Outlast Technologies of the United States obtained a patent license for phase change microcapsule technology from Triangle Corporation and began to produce and market heat-storage and temperature-regulating microcapsules fibers.

In 2000, Jilin Chemical Fiber of China completed the lab-scale trial of bamboo fiber, and it achieved the batch production of bamboo pulp in 2002.

In 2005, polylactic acid (PLA) fiber achieved large-scale commercial production, marking a milestone in the industrialization of bio-based synthetic fibers.

In 2008, Weihai Guangwei Composites of China achieved a breakthrough in the engineering technology of T300-grade carbon fiber, breaking foreign technological monopolies.

In 2015, Zhongfu Shenyang Carbon Fiber Co., Ltd., China achieved the engineering-scale production of T800-grade carbon fiber, marking the entry of domestically produced carbon fiber into the high-end application field.

In 2017, China achieved the localization and large-scale production of Lyocell fiber.

In 2020, the global output of bio-based fibers exceeded 2 million tons. Fibers such as PLA and PHA witnessed rapid growth, establishing bio-based fibers as a core driver behind the green transition of the fiber industry.

In 2022, China achieved a breakthrough in the key technologies for M55J-grade high-modulus carbon fiber, with the performance of domestically produced carbon fiber reaching the international advanced level.

In 2025, International Composite Materials (ICM) launched an ultra-high modulus glass fiber with a modulus of 100 GPa, which is tailored for thermoplastic wind turbine blades. This innovation addresses the challenges in wind blade recycling and facilitates the green closed-loop development of the wind power industry.