Manufacturing Techniques of IOT Hybrid Fiber Materials

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The fabrication of smart fabrics can be divided into coating and lamination processes. Coating methods include dip, knife or blade, air knife, metering rod, transfer, roll, paste dot, and powder. Laminating methods include flame, wet adhesive, hot melt, dry heat, and ultrasonic. Flame lamination is a process in which a prepared thin thermoplastic foam sheet is passed over an open flame to generate a thin layer of a molten polymer. Polyurethane foam (PUF) is the most frequently used foam. Wet adhesives used in the laminating process are either water- or solvent-based. They are applied to the substrate surface in liquid form using conventional coating methods, such as gravure roll coating, spraying, roll coating, and knife coating. Then, the adhesive-coated web is bonded with other substrates under pressure and dried or cured in an oven.

hybrid fiber material | electrical conductivity | shape memory | sputtering | electrospinning

1. Introduction

The emergence of the next-generation Fourth Industrial Revolution is, at present, promoting research on artificial intelligence (AI), the Internet of Things, information and communications technology (ICT), intelligent fibers, nanowires, and smart materials. Consequently, smart wear is becoming an item that will dominate the fiber material industry in the future. Hybrid fiber composites can have various applications, such as in healthcare, defense, fashion and entertainment, sportswear, purpose clothing, and transportation, as well as integration with advanced technology [1][2][3][4][5][6][7][8]. To date, research on cutting-edge hybrid fiber materials is being conducted [4][5][9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27][28][29][30][31][32].

Materials used in smart textiles include shape-memory materials, metal fibers, conductive inks, nanoparticle optical fibers, organic semiconductors, chromic materials, and inheritance-conductive polymers. McCann introduced phase-change materials, thermochromic materials, shape-memory alloys, quantum tunneling composites for switching devices, light-emitting polymers, photovoltaics and solar cells, photoluminescence, plasma technology, microencapsulation for therapy delivery, global positioning, wireless communications, radio-frequency-identification (RFID) tags and microelectronic mechanical systems (MEMSs), and exoskeletons [33][34]. S. Lam Po Tang et al. presented smart-clothing technologies in their research. They suggested that shape-memory materials/polymers, phase-change materials, chromatic materials (thermochromic and photochromic dyes), stimuli-responsive hydrogels and membranes, and smart wearable electronics (conductive materials, flexible sensors, wireless technology, and alternative power sources) could be used as smart technology in the textile industry [35].

2. Manufacturing Techniques of Internet of Things (IoT) Hybrid Fiber Materials

2.1. Sputtering

Sputtering technology thinly coats metal onto the fiber and has an eco-friendly advantage as it does not generate wastewater. In addition, fibers that have introduced sputtering can be used as military stealth materials, smart wear using electrically conductive materials, and artificial intelligence materials [36][37][38][39].

Additionally, there is a study in which metal nanograins, such as aluminum, copper, and nickel, were formed on the fabric through sputtering treatment [40]. The metal layer of the magnetron sputtering fabric rapidly emits the body temperature into the open air, concealing the body in infrared thermal-imaging cameras [41]. However, the effect of stealth technology depends on the sputtering processing time; therefore, the sputtering process must be performed for an appropriate period [40][41]. In addition, a flexible and wearable electrically conductive pressure sensor was developed using $SnCl_4$ treatment and Ag sputtering on nylon. The manufactured pressure sensor was observed to be highly reproducible and repeatable for 9500 repeated mechanical loads, with a low capacitance loss rate of 0.0534. Fabric-based flexible and comfortable sensors can be integrated into fabric garments using thermal pressure. Conductive nylon fabric in the twill structure, which showed a high conductivity rate of 0.268 Ω/cm (specific resistance), was prepared by magnetron sputtering with silver films. The flexible pressure sensor exhibited a high sensitivity value of 0.035 kPa^{-1} [42].

Sputtering technology is advantageous as it is environmentally friendly, has a simple manufacturing process, and produces no wastewater compared to other forms of coating technology. In addition, it has stealth technology, electrical conductivity, and electromagnetic wave blocking in which the thickness of the layer can be easily adjusted according to process changes. Therefore, as it is so versatile, it can be used as a state-of-the-art hybrid fiber in a variety of fields.

2.2. Electrospinning

Electrospinning products can be used for protective materials, structurally colored fibers, self-cleaning materials, adsorbents, electromagnetic shielding, agriculture, low-temperature proton-exchange membrane fuel cells, solid oxide fuel cells, hydrogen storage, supercapacitors, lithium-ion battery materials, dye-sensitized solar cell applications, biosensors and biocatalysis, wastewater treatment, and air pollution control [43][44][45].

The thickness of the electrospun nanoweb was varied to manufacture membranes with different pore diameters. There are three main types of electrospinning devices. The first is a “high-voltage power”, which is usually 50 kV, and the second is “spinneret”, where the nozzle radiating speed is an important factor in determining fiber thickness. The third is the ink collector. The distance between the tip and collector determines the degree of elongation and the fiber thickness. Several studies have been conducted to regulate electro-radiation conditions for various variables.

Bokova et al. addressed fiber electrical rotation technology for nonwoven fabric production in various applications. In particular, they studied the conditions for forming nano- and microfibers in collagen hydrolysate and dibutyrylchitine solutions, as well as polymer complexes based on polyacrylic acid, polyvinyl alcohol, and polyethylene oxide. Comparative analyses of electrical rotations, electrical capillary tubes, and electrical nano spiders were performed. The results show promise not only for garment and shoe production, but also for the application of nonwoven fabrics in pharmaceutical hygiene practices [46].

2.3. Three-Dimensional Printing

Three-dimensional printing is a process that uses additive materials, and the starting products are manufactured by stacking the layers individually. Thus, the CAD model was physically reproduced by individually stacking materials upwards from the bottom. Cross-sectional data is required to create objects because the product is manufactured using the program.

Three-dimensional printing methods are largely solid-, liquid-, and powder-based. Solid-based models include fused deposition modeling (FDM), fused filament fabrication (FFF), and LOM (laminated-object manufacturing).

Fused deposition modeling (FDM), which is the most frequently used 3D printer, is mainly used by PLA(Poly Lactic Acid) and TPU(Thermoplastic Polyurethanes). The FDM-type filament is formed by stacking the material that is melted in the heated extruder and flows out of the nozzle onto a plate. As this method does not use a laser, it has the advantages of being a simple mechanism, having high durability and strength properties, and efficient manufacturing cost and time.

Liquid-based models include SLA (stereolithography apparatus), DLP (digital light processing), Polyjet (photo polymer jetting), and MJP (multi-jet printing).

The digital light processing (DLP) method uses a liquid photocurable resin. Liquid materials are placed in a tank where light can be transmitted, and parts are selectively cured by projecting cross-sectional images of the sculpting object onto the material, using the DLP engine. The DLP method has the advantage of producing low noise levels and sophisticated products; however, if the production size increases, the resolution decreases.

Three-dimensional printers are being used in a variety of fields at present, such as core-sheath fibers, vascular diseases, artificial organs, and intelligent textiles. In addition, previous studies have proposed a 3D-printing model that can be used for valve, vascular, and structural heart diseases [47].

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