Chapter 5

Chitosan's Wide Profile from Fibre to Fabrics: An Overview

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Additional information is available at the end of the chapter

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Abstract

Textile has a high structure capacity, is adaptive to multiple situations and is applied in food, energy, environmental, construction and medical industries. Its stable and flexible characteristics are sure to attract even more attention. Biofunctional textile is one of the most important categories of functional textile, taking up 7% of the total amount, and is expected to be the most promising section of growth. Due to the restrict requirement of fibre production, chitosan is one of the few materials that can be spun into pure fibre. The pure chitosan fibre can be blend with other fibres and produce durable functional fabric suitable for medical as well as daily use. This article also reviewed existed modification on chitosan material prepared for fibre spinning and technology related to chitosan-based textile production and discussed the difficulties and possible solutions in chitosan yarn spinning and possible ways of fabric forming.

Keywords: chitosan, textile, fibres, fabrics, biofunctional materials

1. Introduction

The textile industry accounts for 2% of the world's gross domestic product and is the seventh largest economic sector, according to a recent report by McKinsey & Company [1]. The capabilities and stability of textiles have advanced considerably. Entanglement of fibres in yarns can be designed and fabricated by changing numerous technical factors during production. Furthermore, diverse methods are used for forming fabrics. Knitting and weaving structures differ in elasticity, density and air and liquid permeability. There are numerous methods of enriching textile structures by combining and layering existing structures without adherence between components. Moreover, textiles are considerably more stable than common film structures because of the elasticity embedded in their structure. Textiles are durable under conditions subjecting them to impact forces and are resistant to abrasion. Therefore, the structure of textiles is favoured for both industrial use and apparel.

Advances in material development offer opportunities for cross discipline studies to further improve the mechanical and functional performance of textiles. Textiles are applied in the food, energy, environmental, construction and medical industries, meaning they are not only a domestic product. Their stable and flexible characteristics have attracted considerable attention. Functional textiles account for 27% of worldwide fabric production, with the functional textile market expected to be worth US$175 billion by 2020.

Biofunctional textiles are among the most valuable categories of functional textiles, accounting for up to 7% of total functional textiles. Developing countries involving growing textile industries, such as China, have lost global textile and apparel market share. The textile market has shifted to more value-added products, namely technical textiles. Biofunctional textiles are categorised according to their usage: in vitro and in vivo use. Biofunctional textiles for in vivo use emphasise biocompatibility and biostability because they come into direct contact with cells and biological fluids. One method of endowing these capabilities in a textile is by coating a textile polymer with functional molecules, which is sometimes enhanced through chemical bonds. However, the coating is thin and vulnerable to abrasion and other physical movements, even when the environment of application is in vivo. Another means of developing biofunctional textiles is by spinning fibres with pure functional materials. Candidate materials for spinning fibre are extremely limited because of both process requirements and mechanical properties of the fibre required for yarn spinning.

The two main methods of forming fibres are melt and wet spinning. Melt spinning is typically applied to thermoplastic polymers that transform to a liquid form under heat and recover to a solid and flexible form after cooling. The mechanical and functional properties of the fibre should not be affected by the high temperatures required in melt spinning.

Such a requirement of melt spinning is hardly achieved by biofunctional fibre materials, such as chitosan and alginate, because they are not thermoplastic and also degrade when heated at elevated temperatures. In such cases, low-temperature wet spinning or gel spinning is used. In wet spinning, the polymer is dissolved in a solvent and then extruded through a spinneret into a nonsolvent in a coagulation bath in which the fibres are precipitated and solidified. The filaments are then washed to remove the remaining solvents and nonsolvents, drawn, dried and lubricated before being wound on a bobbin. Other solvent removal methods exist. Instead of precipitating the fibres in a coagulation bath, dry spinning involves solidifying the fibres by evaporating the solvent in a stream of hot air or hot inert gas. The solvent is recovered and reused in such a method.

The strict requirements of fibre spinning and the fragility of biofunctional materials limit the material choices for pure biofunctional fibres. Typical pure biofunctional fibres are made from corn, bamboo, milk, microorganism products and animal shells. The first four material sources are developed mainly as a substitute for oil-based manmade fibres, whereas the fifth material source has special biofunctions other than biocompatibility and biostability.

Chitosan and chitin fibres are the products of such technology, which inherent the antibacterial and wound-healing characteristics of chitosan and chitin materials while holding adequate mechanical strength.

2. Chitosan textile production

Traditionally, chitosan is mainly treated on a yarn's or fabric's surface [2–6] and is exposed to harm from abrasion and other movements. Chitosan peals when it wears, and the biofunctions are vulnerable to physical and chemical damage. Producing a pure fibre from chitosan is a reasonable means of improving stability and durability.

Chitosan fibres are derived mainly from wet spinning. Dissolution, deaeration and filtration of chitosan are performed before spinning [7]. The semi-finished fibres are then refined, dried and post-finished. Factors in dissolution, deaeration and drying are vital to control properties of chitosan fibre, including solvent, pH and concentration during dissolution, method and agent of drying, etc. A study [8] shows that methanol drying yielded chitosan fibre has superior mechanical properties to fibres dried using other methods and agent.

The three main methods are available for producing a fabric from fibres. A nonwoven method entails entangling fibres by using water or air jets. This process is similar to wool felting and requires no yarn spinning. The nonwoven method is fast and cheap, and it is suitable for producing cheap, disposable products. Woven and knit fabrics are more durable and are more suitable for daily use because they can be reused hundreds of times, withstanding frequent washing and abrasion [9, 10] (**Figures 1**–**5**).

Chitosan fibres are weaker than cotton. Typical chitosan fibres have a dry tensile strength of 2.09 cN/dtex, which is close to the minimum dry tensile strength value for cotton fibres (1.9–3.1 cN/dtex). Their wet tensile strength (1.8 cN/dtex) is lower than that of cotton fibres (2.23.1 cN/dtex) (**Table 1**). In a spinning factory, the humidity is usually set to a high level (70–80%), under which conditions chitosan becomes adhesive and weak, causing problems during the spinning process, especially when yarns have a high chitosan fibre ratio.

Chitosan's weakness also affects end-product usage. A weak textile does not withstand tearing, bursting or abrasion. Therefore, the strength and weakness must be balanced by mixing and strengthening the fibre with other materials. The price of chitosan and fibres is expensive at up to $100 per kilogramme, which is comparable to cashmere. The blending of two or more types of fibre solves both the mechanical strength and cost problems.

Blending two or more biofunctional materials or blending biofunctional materials with non-biofunctional materials can be achieved during fibre spinning, yarn spinning or fabric formation. Blending in or before fibre spinning requires property consistency between the two or more biofunctional materials in the spinning process; the ratio of biofunctional materials is settled and less flexible regarding the production process. Blending after yarn production is likely to cause an uneven distribution of the biofunctional materials and influence the performance. A balanced method of forming blended fabric requires the blending of pure fibres during yarn spinning.

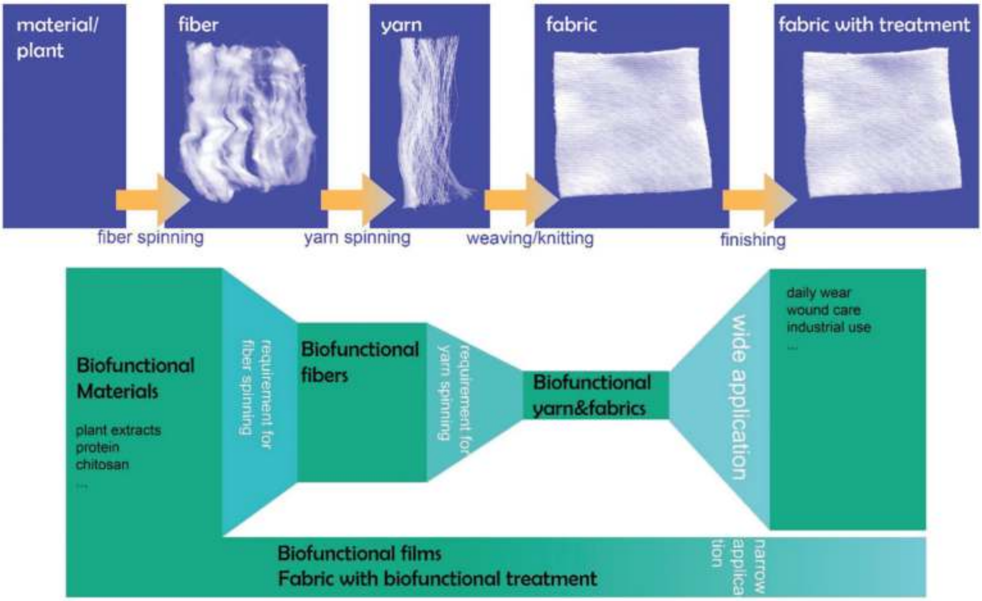

Figure 1. Process of textile production (upper); the strict requirements of textile production heavily restrict the applicable material list (chitosan is an example). The rich structural capability and stability of biofunctional textiles render them versatile.

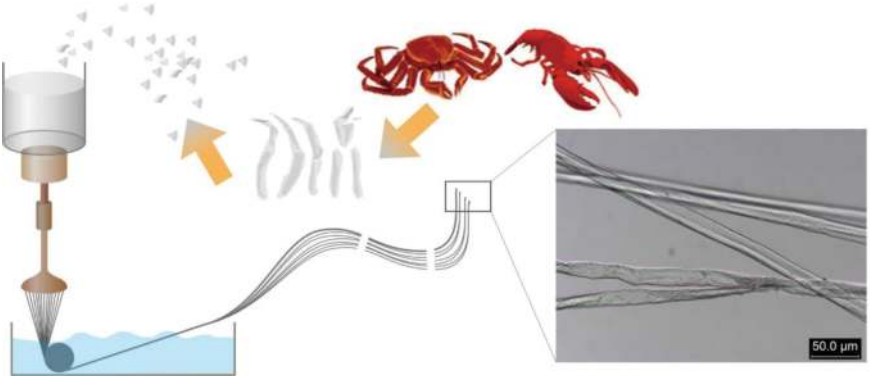

Figure 2. Spinning process of chitosan fibre (left) and chitosan fibre under microscope (right).

Blending biofunctional fibres during yarn spinning may cause problems. Biofunctional fibres normally have weaker mechanical properties than normal fibres, but they may have special properties. Chitosan fibres easily adhere to rubber rollers, which not only causes difficulty in spinning yarns with a high chitosan content but also causes material loss, raising production costs. Therefore, the mechanical properties and biofunction of yarns must be carefully balanced to ensure sufficient strength and comfort handle and maintain stable biofunctions while controlling the production difficulty and costs.

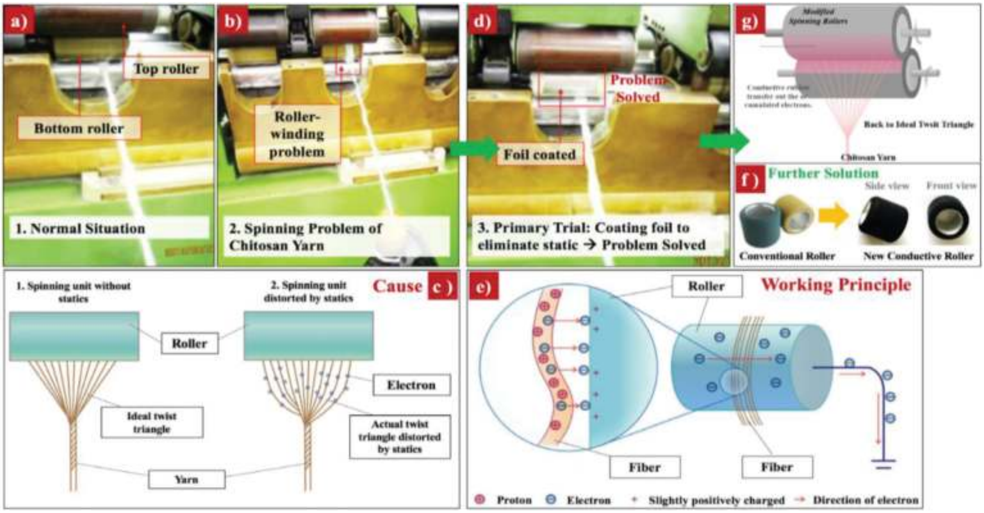

Figure 3. (a) Normal situation of spinning a twist triangle; (b) roller-winding problem faced during the spinning of chitosan fibres; (c) analysing the cause of the problem: adhesion caused by static electricity is easily generated by abrasion (due to the extremely low electronic work function of chitosan fibres); (d) primary trial to solve the problem by using a layer of foil to remove (transfer) accumulated electrons; (e) working principle of the primary trial; (f) further trial: modified conductive roller to remove the static electricity; and (g) a twist triangle turns back to an ideal situation when the modified rollers are applied.

Figure 4. Example of product design targets epidermolysis bullosa patients.

Studies [11–13] have shown that factors associated with the blending process, such as blending time (fibre or sliver blending) and spinning factors, may influence the distribution of yarn fibres. Regarding the ratios of biofunctional fibres, variables must be examined not only for academic purposes but also for industrial and domestic application. Efficient and precise testing methods must be developed to facilitate the regulation of biofunctional textile production, testing and usage.

Figure 5. Four common biofunctional materials related to wound care: Band-Aid, gel dressing (artificial skin), powder or cream and textile.

Parameters	Values	Cotton*
Dry tensile strength (cN/dtex)	2.09	1.9–3.1
Dry tensile strength ratio (%)	15.1	7–10
Wet tensile strength (cN/dtex)	1.80	2.2–3.1

*Source from www.intechopen.com

Table 1. Parameters of chitosan fibre.

Besides blending after fibre spinning, blending before fibre spinning and chitosan material modification are other common ways for researchers to reinforce the weak fibres especially in wet and acidic environment. Blending chitosan with other polymers can strengthen the fibre but compatibility needs to be improved, and thus reactive compatibilisers such as epoxy-functionalised LDPE has been introduced to increase the strength of the blend [14].

Biofunctions of chitosan/chitosan-treated fabric can be improved by adding functional groups on chitosan material or adding other ingredients. Some approaches make reaction faster by improving chitosan water solubility by acylation, alkylation, pegylation, hydroxyalkylation, carboxyalkylation and depolymerisation, but the durability is sure to be shortened. Some others improve cationic properties by deacetylation, quaternisation and addition of cationic moieties. Concerning non-toxic requirement of chitosan textile for medical use, some safe additives include neem [15].

Cross-linked chitosan fibre shows equal [16] or better [17] antibacterial effect and possibly has better mechanical property due to the reduction of crystallinity [18]. Stronger antibacterial function is found in N,N,N-trimethyl chitosan fibres [19] and succinic anhydride-modified fibre [20]. N-carboxyethyl chitosan fibres [21], quaternisation-functionalised chitosan fibre [22] and succinic anhydride-modified fibre [20] have better liquid absorption capacity than normal chitosan fibre, but tensile strength and elongation at break are lower. There are few studies that clearly report improvement in both mechanical and biofunction properties.

3. Application of chitosan textile

Chitosan textiles can be used for medical care to provide safe and continuous protection for patients and caregivers. For patients with skin trauma, particularly those who are bedbound and at risk of developing bedsores, or those with low immunity, chitosan textiles can be used as materials for daily dressing and bedding or as fundamental materials for long-term wound care [23]; this is because such textiles control bacterial growth and accelerate wound healing. Moreover, chitosan textiles can avoid or reduce the side effects of long-term antibiotic or silver fungicide use. The antibacterial function can be controlled by the blending ratio of the chitosan fibres to other fibres to meet different needs.

Chitosan textiles are also required in space and military activities. The extreme environment in space renders the balance of microorganisms even more vital. Excessive or insufficient microorganisms can pose a risk. An excessively high number of microorganisms pose an infection risk. Furthermore, the growth and mutation of bacteria in space are uncontrollable, which may pose a threat to humans and other on-board animals. An excessively low microbial population may cause immune disorders or impaired immune function. Using chitosan textiles in ship interiors and clothing can continuously maintain the number of microorganisms, which is beneficial to the health of shipborne personnel.

In addition to special uses, chitosan textiles can be used for ordinary clothing, especially underwear. The market demand for antibacterial underwear is considerably high. In relatively hostile market environments, functional underwear can be marketed as having advantageous properties over products of competing enterprises, in order to prevent the prices from being trapped at low levels. In contrast to chitosan antibacterial agents coated on the surface of normal fabrics, blended chitosan-knitted fabrics do not lose their biofunctions after friction or washing. The antibacterial performance of the fabrics is still stable after being washed hundreds of times. Therefore, such fabrics are particularly suitable for end products such as underwear, which must be washed frequently. The safety of chitosan-knitted fabrics is also superior to that of traditional silver-based antibacterial fabrics, because they can come into direct contact with the skin.

Chitosan also have antifungal effects [24–29], which render chitosan textile particularly useful for bedding, home decor and personal hygiene products. However, chitosan fibres are not bright or white, which limits the consumer acceptance of chitosan textiles.

4. Conclusion

Further development of relevant technologies will give chitosan textiles a more crucial role in functional textiles in the future. Producing daily wear from a blended fabric with a low proportion of chitosan will ensure that the price is acceptable to consumers. However, chitosan fabrics with special properties generally require a high proportion of chitosan fibres. This requires breakthroughs in spinning technologies, because chitosan fibres are sticky and easily generate static electricity. The upper and lower limits of the functions of chitosan fabrics deserve attention. Because of the high price of chitosan fibres, increasing their proportion should engender greater functional improvement.

Tuning the biological function of chitosan and increasing the ratio of chitosan in fabrics both require a systematic study of blending technologies. Even in the traditional spinning process, numerous parameters may affect the distribution, feather, yarn thickness and compactness of the final fibre. For chitosan yarns, these parameters may affect wet gas absorption, comfort, biological function and the mechanical properties of yarns and fabrics. Results from studies on the textile industry could be used to strengthen the function of chitosan textiles. Meanwhile, factors influencing the structure and effects of chitosan textiles can be eliminated in yarn spinning and during knitting, weaving or felting processes of nonwoven fabric to improve the effects of the final product.

Relevant test methods and standards for chitosan textiles must be further standardised. Chitosan fibre-blended textiles are different from textiles treated with traditional antibiotics or silver fungicides. In contrast to treated fabrics, bactericidal components are insoluble in chitosan fibre-blended textiles. Furthermore, the antibacterial properties of chitosan fibres may not be detected by certain test methods such as those that entail testing the zone of inhibition.

Meanwhile, the method proposed in most studies for testing the antibacterial effects of chitosan in a liquid form after it has been dissolved in an acetic acid solution is not suitable for chitosan textiles, because this situation would not occur in practical use. After existing test methods and determination methods are compared, a comprehensive test system should be developed for chitosan textiles. Furthermore, the antibacterial principle of chitosan fibres may be different from the antiseptic principle of the acetic acid solution for chitosan raw materials. Therefore, studying their differences and similarities is necessary. Moreover, the production of chitosan raw materials causes pollution problems that must be solved. Chitosan textiles have been continuously refined. It is expected that many new findings and technologies will be discovered and developed in this cross domain.

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