Application of chitosan in the form of textile: production and sourcing

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Abstract

Chitosan material has multiple functions that attract attention from the textile industry, while textile structures make the biocompatible, osteo-conductive and resorbable material promising in a wide range of applications. When the material becomes fibers, the resulting length, strength, fineness and softness would grant the material functions such as structure capacity and a layering system. However, the expected win-win situation is not seen in reality. Special properties of the chitosan material may burden its way of application. In addition, market recognition of chitosan, differences between chitosan, chitin and seaweed fibers, differences in antibacterial post-treatment, testing standards of chitosan, antimicrobial and antibacterial treatment in downstream production and fuzzy concepts of users are also concerns and challenges related to chitosan. Gaps and misunderstandings between the supplier, manufacturer, consumer and researchers are clarified. Testing standards are compared by their purpose, mechanism and scope, while in this article, more attention is given to the application side. Existing forms of semi or final textile chitosan products, fabrication process and evaluation methods are reviewed and discussed for their feasibility towards application. In the end, a product development process flow is given marking concerns in each step of production to guide production and sourcing.

Keywords

Management of product: systems, product and systems engineering, management of production: systems, product and systems
engineering, performance, materials, manufacture, fabrication, testing, fiber, yarn, fab ric formation

Introduction

Chitosan is a copolymer of glucosamine derived using the alkaline deacetylation of chitin, which is a natural polysaccharide obtained from the shells of crustaceans such as crabs and shrimps that possess numerous advantages, such as biodegradability, nontoxicity, and unique antimicrobial properties and wound accelerating effects. Technological developments have altered the role of textiles from that of a supplementary material to that of a primary material. Success in chitosan and fiber production has allowed chitosan to be applied on the surfaces of nonfunctional fabric bases as mentioned in various literature,[1,2] moreover, chitosan can be used as a blend with other materials or used alone in its pure form. This development allows chitosan

to perform its desired functions without the need for any further treatment or finishing processes. The production of chitosan fiber has recently attained industrial maturation, but the expected win-win situation is not seen much in reality.

Textile technology is one of the most ancient technologies that involve fiber, yarn, and fabric. Compared with other similar structures, such as film, fabric has advantages such as high strength, elasticity, and permeability. These characteristics are vital for applications involving human skin. In the bio-textile industry, active materials are usually coated on ready-made fabrics as finishing;[3,4] however, the coating may not firmly bind with the fabric and can easily become unattached and lose its function. The biofunction of chitosan material has drawn the attention of the textile industry because its antimicrobial properties have been discovered.[5] However, instability of the chitosan material in environments of pH lower than 7 is a big concern, as well as the disadvantage of weak strength, owing to its chemical structure. Also, as mentioned by recent reviews, there are still plenty of challenges, including poor durability and solubility on textile surfaces, problems of mechanical strength and fiber reactivity, necessity of optimization of morphology and environmental issues occurred during production such as pollution and harmful substances.[1,3]

The literature on the antimicrobial performance of chitosan is extensive, most of which studies chitosan in solution form. However, few studies involve chitosan in its fiber form, not to mention in high-content chitosan-blend yarn forms or in fabric forms, while a few of them mention chitosan coated on cotton,[6,7] wool,[8,9] and viscose[10] fabrics. Some of the studies[6,10] involved antibiotics which hinder horizontal comparison. Because of the complex production process, physical and chemical changes in chitosan may alter its antimicrobial performance; this phenomenon requires further investigation. Furthermore, existing testing methods are based on the medical method of minimum inhibitory concentration (MIC), yet these methods are not applicable to wound conditions. Disagreement and uncertainty exist in the industry concerning testing standards suitable for this new product with unique characteristics.

Textile product development usually start from synthesis of fiber, no matter the fabric formation method. Except some nonwoven sheet/fabric production, most of the textile formation process starts with selection of fibers. Then, it goes through a series of fabrication procedures before launch to the market (as shown in Figure 1 for chitosan). This definitely requires material information, fabrication techniques, and strategic planning. It is thus not surprising that manufacturers are reluctant to develop

chitosan textiles in fiber form as there is not enough information available. A manufacturer who is informed of a new material is likely to gather as much information from material suppliers or other sources as they can; meanwhile they may also contact lower stream buyers to find out the acceptability and marketability. Nevertheless, concerning chitosan textile products, limited information is available on criteria of its selection, testing standards and development processes. Manufacturers may not have a clear picture of chitosan and eventually are not able to promote it. This adversely hinders the development and application of chitosan as a functional textile material.

Figure 1. Procedures of raw materials to fabric in the chitosan textile industry.

Therefore, in this article, existing forms of semi or final textile chitosan products, fabrication processes and evaluation methods are reviewed and discussed for their feasibility towards application. Gaps and misunderstandings between the supplier, manufacturer, consumer and researchers are clarified. Then, existing testing standards are compared by their purpose, mechanism and scope, while in this article, more attention is given to the application side. As the production chain/flow is likely to be complicated and involves multiple stakeholders, a product development process flow is given while obstacles that may occur in each step are indicated, so that an industry chain participant can preview possible difficulties in bringing this promising material to the textile and apparel market.

Material selection

Literature regarding chitosan in the soluble state is numerous. Although no conclusions on the nature of chitosan's mode of action in inhibiting microorganisms have been established, studies have suggested that the interaction of chitosan molecules with cell membranes causes disruption of functions of the outer and/or

inner membranes and leakage of intracellular components. Studies[11] have also reported that the chitosan molecule enters the cell body and interacts with bacterial DNA, which leads to improper function of genetic expression and interferes with the nutrient supply. The second action is unlikely to occur with chitosan in its solid state because the molecule is extremely large and condensed and will not penetrate the cell membrane or enter the cell body.[12−14]

The source of chitosan material is mostly from shells of marine animals. Merchandisers usually label the dried shells by animal names and original country, while the raw material under the same name can differ in quality and cause difficulty in later fiber production. The dried shells are deacetylated before being prepared into gel that is ready for process spinning. Except some basic testing such as water and ash content, evaluation of raw material quality is very limited because of the complex content of natural material. Another option for the fiber manufacturer is to buy deacetylated shell flakes. These flakes are easier to evaluate as they are easily dissolved in acetic acid. Inspectors can obtain information such as viscosity average molecular weight, and deacetylation degree. Meanwhile, shell flakes carry more information of the material source and can be more easily traced.

According to Qin et al.,[15] the solubility of chitosan decreases considerably at pH values higher than 6, and as previously mentioned, studies have demonstrated that chitosan is more soluble in aqueous acetic acid than in pure water. Naive chitosan with relatively higher Mw is not soluble in water. In the context of textiles, materials suitable for fiber spinning will be insoluble while those used for the finishing process will be soluble. Our study of chitosan from six market sources shows that the viscosity molecular weights (Mw) range from 0.35 to 1.06 kDa. These fibers are insoluble in a neutral environment.[16]

The most common pH environment for antimicrobial performance for chitosan ranges between 5 and 6,[17,18] as it is a requirement of the MIC assay, widely adopted in antimicrobial tests, to use a liquid testing material. However, acidic environments influence bacterial growth. Liu et al.[19] conducted a comprehensive study on the antimicrobial effect of acetic acid against *Escherichia coli*, and the results indicated that acetic acid with concentrations over 0.01% displayed an inhibitory effect on *E. coli*, and acetic acid with concentrations over 0.02% killed all the bacteria. In the preparation of chitosan solutions, 1% acetic acid is usually used to achieve a chitosan concentration of 1%, and sodium hydroxide (NaOH) is usually used to adjust the pH to between 5.6 and 5.9. Therefore, it is expected that the concentrations of acetic acid

and chitosan are similar in the final testing dilution. The MIC of chitosan varies due to the difference in Mw, the deacetylation degree (DD), species of microorganisms and conditions, but generally range from 0.025% to over 0.2%, which exceeds the 0.02% threshold concentration. In a study by No et al.,[18] the effect of pH (4.5 to 5.9) on bacterial species, including *Staphylococcus aureus* and *E. coli*, was evaluated using a 0.03% chitosan solute in similar concentrations of organic acid and acetic acid. *E. coli* had 8.93 viable cell log numbers at 4.5 pH, and 9.54 at a pH of 5.9. The effect on *S. aureus* was even less (8.53 at 4.5 pH and 8.50 at 5.9 pH). Some studies[15,19] have suggested that low-pH chitosan solutions displayed improved antimicrobial performance. However, whether the promotion effect is merely due to the lowering of pH as indicated by Percival et al.[20] or the interaction between chitosan and acetic acid remains uncertain.[21]

Apart from articles relating to chitosan solutions with a pH of less than 6, few studies on chitosan in solid state have been conducted. Compared with chitosan in the solute state, chitosan in solid state possesses only limited conformation contact with the medium of microorganisms. Kong et al.[22] stated that the mode of action of chitosan in the solid state might differ from that of chitosan in solution form. Hydrophobic and chelating effects are relevant in solid states; however, the dominant electrostatic effect is relevant in the solute states. Therefore, the evaluation of chitosan material prepared for fiber spinning will not be the same as that for coating or film fabrication.[17] Key parameters such as molecular weight and deacetylation degree that may later influence performance in the fiber state will be tested for quality control in later production. The effect of Mw is still a mist, as some studies show that longer chain chitosan has better activity against bacteria,[23] while some indicate the opposite.[24] The others claim that there is a more complex relation that dependS on the bacteriaL strains,[18,25,26] or there is no significant relation at all.[17,24] If the manufacturer considers using chitosan as coating material, the criteria may differ. Fernandes et al.[17] conducted a comprehensive experiment on chitosan in solution and padded on cotton fabric. The authors included three types of chitosan with high to low Mw (averaging 591, 628, and 107 kDa) and two types of chito-oligosaccharide (Mw <5 and <3 kDa) for gram-negative bacteria. Lower Mw chitosan was found to have higher inhibition performance, and the results were the reverse in the case of gram-positive bacteria. Such results may be due to the structural difference between the two groups. The oligomer more easily penetrates the cell wall of gram-negative bacteria.

Apart from the antimicrobial performance, manufacturers may have to be aware of the impact on physical properties of end textile products by chemical processing. The

study of Benltoufa et al.[27]pointed out that tensile behavior, thickness, air permeability and comfort level are all affected by antimicrobial treatment. Also, the antibacterial rate of coating methods reduces to around 90% after laundering for five[28] and 10 cycles[29] (Figure 2).

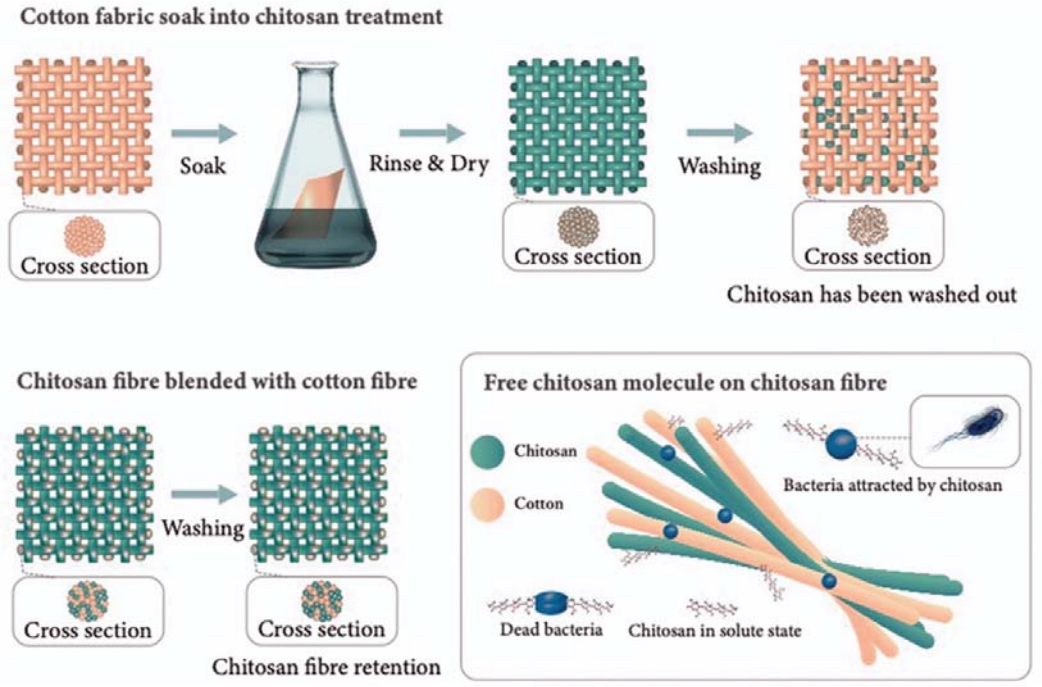

Figure 2. Chitosan as treatment and blended fiber in fabric (left) and mode of action by chitosan on bacteria (right).

Fiber selection: testing method and standards

A more common entry point for the textile manufacturer is to source chitosan fiber. Chitosan fibers are produced by gel spinning. Chitosan flakes or powder are dissolved in acetic acid solution before being injected through a spinneret. Although the velocity of gel can be easily adjusted to a proper level, antifoaming is a great challenge, because bubbles in gel cause unevenness and flaws in the fiber. Meanwhile, heating and string in the dissolving process may break polymer chains and affect fiber performance. Besides characterization on normal textile-wise parameters such as fineness and strength, special tests of molecular weight and DD are required for chitosan fiber evaluation. In research practice, these parameters can be achieved by gel permeation chromatography (Mw)[30,31] and first derivative ultraviolet (UV) spectrophotometry (DD).[32] Some of the methods, however, are not applicable in the manufacturing context. For example, molecular weight characterized by viscose testing is more practical and at a lower cost.

The antimicrobial property of fiber is also a big concern of the manufacturers as it will decide the property of the final product. The MIC is one of the most popular quantitative methods that is seen in many studies about chitosan,[17,33,34] and is defined as the lowest concentration of an antimicrobial that prevents the visible growth of bacteria over a defined period (usually less than 1 h). The minimum bactericidal concentration is the lowest concentration of an antibacterial agent required to kill a bacterium over a defined period (usually 18 or 24 h). Another fast method is the optical density method which monitors microorganisms with 610 nm.[19] Such methods are relatively quick and inexpensive; however, they are only effective in soluble antibacterials with a strong killing effect. Existing antimicrobial test standards in the context of textiles differ in the method of contact, time of contact, sample–microbe ratio, microbial media, nutrition, reference strains, and evaluation method. The most significant difference is the contact method. The contact method involves samples being inoculated on solid medium; the absorption method requires samples to be inoculated with liquid medium before being placed on solid medium; the transfer method requires samples to be inoculated using surface inoculated solid medium. The shaking method does not involve solid medium, and samples are directly placed in inoculated liquid medium. It is important to note the necessity to distinguish chitosan materials from chitosan fiber, because the antimicrobial properties tested from the raw chitosan material do not reflect the antimicrobial properties of the fiber products.[16]

The most important step in the testing process is the way of bacteria contacting the textile. Common ways of contact include (dry) contact, absorption, shaking and transfer. The dry contact method means the uninoculated sample is directly placed on inoculated agar medium; the absorption method means the sample absorbs bacterial inoculum; the shaking method means the sample is immersed in bacterial inoculum and shaken violently; the transfer method means bacteria are inoculated on another medium and transferred on to the sample by contact. Shaking methods are most suitable for non-soluble chitosan textiles. In principle, fibers/fabrics are immersed in liquid containing microorganisms and shaken dynamically. Changes in viable count in percentages or logarithm difference are used to quantify the performance.

In the same category of shaking methods, there are many differences of details in vessel choice, contact time, initial inoculum size, sample–inoculum ratio, nutrition/growth of bacteria on control, strains, temperature, sterilization method, quantitative methods, evaluation methods.

Vessel

In standards with a shaking method of contact, the shape and volume of vessels influence the bacterial growth and contact efficiency of the sample in liquid. A 250 ml glass vessel is mostly suggested as the liquid volume is mostly around one-third of the vessel. In the chitosan textile test, a liquid volume of more than half of the vessel may result in failure to detect any inhibition effect for a sample with over 95% of inhibition rate.

Contact time

In most standards regardless of the way the sample contacts bacteria, contact time is set at 18–24 h, meaning 'overnight'. For most test strains, bacteriaa growth goes to a stationary phase at that time, and the active ingredient is expected to have totally performed its function. The ASTM E2149-10 standard has a special contact time of 1 h. Studies[19] have shown that the chitosan antibacterial effect peaks at a certain time and weaken afterwards, and it is stated that chitosan even promotes the bacterial growth after a certain time, but the studies referred to acid solute chitosan. Whether a similar behavior is applicable to chitosan textiles requires further study.

Initial inoculum size

Inoculum that is applied on to fabric contains bacteria in the log phase. The absorption contact method usually has a larger inoculum concentration, while the inoculum volume is smaller. But even under similar contact principles the initial inoculum can be different. For example, in standard ASTM E2149-10 the initial inoculum concentration is $1.5–3.0 \times 10^5$ colony-forming units (CFU)/ml, while in standard FZ/T 73023 the initial inoculum concentration is around 1.8×10^4 CFU/ml, noting that contact times in the two standards are different.

Sample–inoculum ratio

In AATCC100, the number of swatches to be used is dependent on the fiber type and fabric construction. Use that amount of fabric that will absorb the 1.0 ± 0.1 ml of inoculum and leave no free liquid in the jar. In FZ/T 73023 the initial inoculum concentration is $1.5–3.0 \times 10^5$ with1.0 ± 0.1 g.

Nutrition/growth of bacteria on control

Although it may not be specified in most standards, the nutrition level is critically important to the inhibition performance of the sample. As conditions and suppliers are uncontrollable variables, the nutrition level is usually regulated by controlling the growth of bacteria on control samples. Bacteria with a lower nutrition level results in

better results of inhibition, as the bacteria tend to be weaker in such conditions. Therefore, most standards limit the lowest growth of bacteria on the control sample to 100 times.

Temperature

The temperature of culturing in absorption methods are fixed to 37 ± 2°C, while for the shaking method the temperature is set at 24 ± 1°C in FZ/T 73023 and is not defined in ASTM E2149-10. The absorption method imitates the environment on skin and the shaking method tests whether bacteria accumulate on fabric near the body.

Sterilization method

In all standards, textile samples are suggested to be sterilized by autoclave. However, chitosan is more vulnerable to heat. The molecular weight of chitosan material may decrease and influence the antibacterial performance. It is suggested that samples sterilized by UV, oxirane or γ-ray.

Quantitative methods

The plate count is reliable and requires less equipment and fewer reagents and most are adopted. The adenosine triphosphate (ATP) concentration of the bacterial suspension is adopted in ISO 20743:2013.

Evaluation methods

Typical methods with the absorption principle calculate the killing rate. As chitosan inhibits the growth of bacteria rather than killing bacteria, the results can be minus and there is a risk that an effective sample can be reported as ineffective. Therefore, the inhibition rate is in most cases more applicable in quantifying the performance of chitosan under pH over 6.5, or the two results will be reported in the same time.

Killing rate

$$= \frac{\text{viable count at 0 h of sample fabric} - \text{viable count at 24 h of sample fabric}}{\text{viable count at 0 h of sample fabric}} \times 100\% \quad (1)$$

Inhibition rate

$$= \frac{\text{viable count at 24 h of control fabric} - \text{viable count at 24 h of sample fabric}}{\text{viable count at 24 h of control fabric}} \times 100\% \quad (2)$$

In fact, some standards have combined the two judging methods. ISO standard (ISO 20743:2013) regulated inhibition evaluation with the antibacterial activity value ($A = (\lg C_t - \lg C_o) - (\lg T_t - \lg T_o)$, C_t is the viable count after contact time of the control fabric, C_0 is the viable count before contact time of the control fabric, T_t is the viable count after contact time of the tested fabric, T_0 is the viable count before contact time of the tested fabric). Standard JIS L 1902 also compared the viable count after a certain incubation time of the sample fabric with that of the control fabric regardless of whether the fabric kills or inhibits the growth of bacteria. The difference in qualitative judgment is shown by the threshold instead of the calculation method, which increases the consistency. Table 1 and Figure 3 show a summary of related standards and testing methods.

	Standard	Method and description
(1)	AATCC147-2011 AATCC174-2011	Method: Contact. Drawing parallel lines on nutrient agar with diluted incubated test bacterial inoculum in nutrient broth. Sample piece put on agar and the inhibition zone is measured after contact time.
(2)	AATCC 90-2011 ISO 20645-2004 FZ/T 73023-2006	Method: Contact. Nutrient agar spread on evenly with diluted incubated test bacterial inoculum in nutrient broth. Sample piece put on agar and the inhibition zone was measured after contact time.
(3)	JIS L 1902:2008	Method: Contact. Incubated test bacterial inoculum is blended with nutrient agar. The sample piece is put on agar and the inhibition zone is measured after contact time.
(4)	GB/T20944.1-2007	Incubated test bacterial inoculum is blended with upper layer of nutrient agar. Sample piece is put on the agar, and the inhibition zone is measured after contact time.
(5)	Quinn test FZ/T 73023-2006 FZ/T 62015-2009	Method: Contact. Bacteria are incubated on sample and contact to agar. Number of colonies is counted after contact time.
(6)	ISO 20743-2013 FZ/T 73023-2006 FZ/T 62015-2009 GB/T20944.2-2007	Method: Absorption. Incubated test bacterial inoculum in nutrient broth is absorbed by the sample, and the reduction/inhibition rate of bacteria after contact time is measured.
(7)	ASTM E 2149 GB/T20944.3-2008 FZ/T 73023-2006 FZ/T 62015-2009	Method: Shaking. Diluted test bacterial inoculum in nutrient broth immerse sample and measure the reduction/inhibition rate of bacteria after shaking.
(8)	ISO 10743	Method: Transfer. Nutrient agar is spread on evenly with diluted incubated test bacterial inoculum in nutrient broth. Sample piece is put on agar to transfer bacteria on sample. Reduction/inhibition rate of bacteria is measured after contact time.

Table 1. Related standard and description

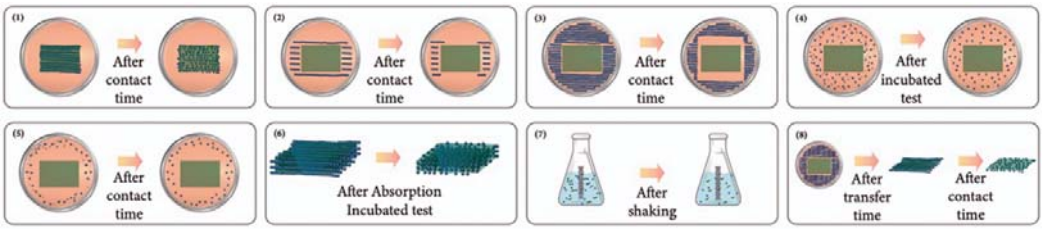

Figure 3. Anti-microorganism testing method in textile content.

Blending is a commonly used technology in the textile industry. In this process, fibers are mixed either before or during the spinning process. If the active material can be spun into fiber and blended with inactive fiber material, the durability and

permeability can be significantly improved, while preserving the advantages of fabric structures[35] (Figure 2).

Textile fabrication process

Once chitosan fiber is fabricated, it seems natural to include this cotton-like fiber in the normal production stream. However, it is unwise to assume that chitosan fiber can be treated as a conventional synthetic fiber. Although it is expected that chitosan used as a treatment on textiles does not alter the chemical structure of the textile material (and thus the treatment has a negligible effect on its biological performance), the production process of fiber, yarn, or fabric may affect the key parameters and thus affect performance.

As shown in Figure 4, chitosan fiber may contain creases, twists and small particles due to a high degree of deacetylation. Also, the breaking strength of chitosan fiber is as low as 0.5 to 2 cN/tex, which is weaker than that of cotton fibers (1.8∼3.1 cN/tex).[16] Its mechanical weakness and stickiness may cause problems in the yarn spinning process. In the textile machinery industry, rollers usually have rotating cylinder parts that feed, draft, or output yarns or semi-yarns. The drawing roller is one of the most important parts in the machinery and consists of two parts: the top roller and bottom roller. The two parts hold and simultaneously draft the roving to form a yarn. The quality of rollers directly affects the quality of yarn in terms of strength, evenness and hairyness. In the current machinery, to hold fibers firmly and evenly without harm to the fiber, elastic material is always used on the roller surface. The most popular choice of material is nitrile rubber. Because of the significant work function gap between the roller and fiber materials, electrostatic force can be accumulated at high levels. If the electrostatic force is not exported in time, the fiber will wind on the roller and cause yarn unevenness and sometimes pauses in production.

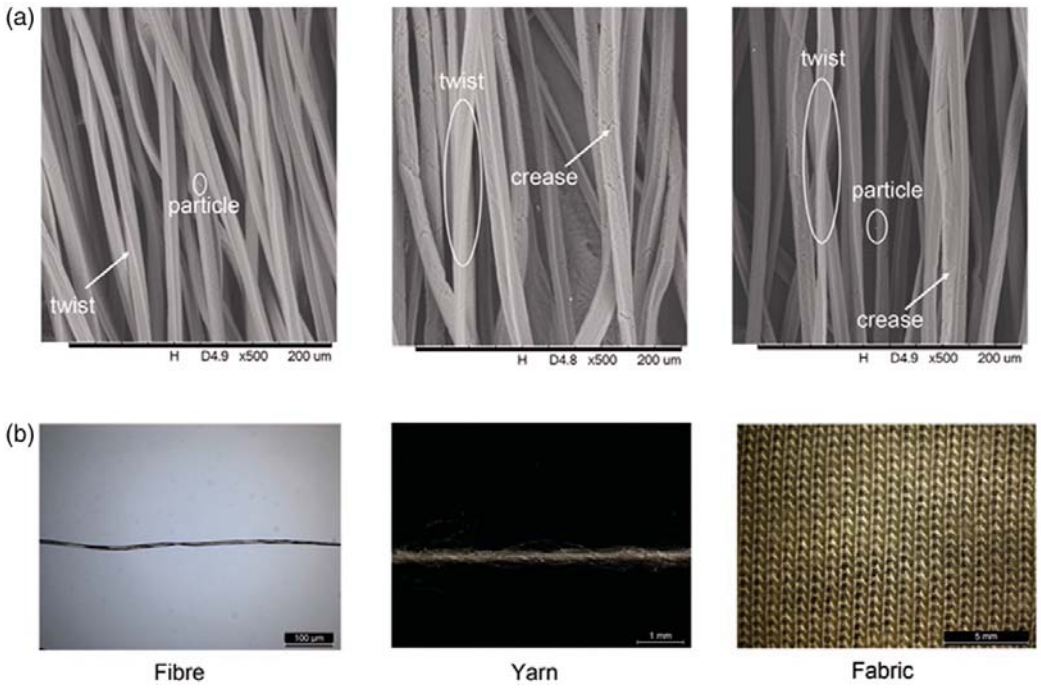

Figure 4. (a) Scanning electron microscopy (SEM) images of fiber sample showing various morphological characters of chitosan fibers; (b) microscopic images showing chitosan fiber, yarn and fabric (knitted).

For apparel applications, chitosan fiber usually ends in woven or knitted fabric with a 10/90 blending ratio. The shortcomings of chitosan fiber, such as high electrostatic generation and poor mechanical properties, restrict the application of chitosan in yarn-based textile production technology, which explains the lack of literature on high-percentage chitosan spinning, weaving, and knitting technology. In the medical and hygiene fields, the main end products are wound pads, which consist of spun-laced or hot-blast nonwoven fabrics. Most common blends in the nonwoven category include 15/85 chitosan/viscous and 15/85 chitosan/tencel. However, chitosan percentages in these blends can reach as high as 30%, 50%, or even 100%. The weight per square of chitosan nonwoven fabrics ranges from 35 to 80. On one hand, hot-blast nonwoven fabric offers low-cost identity; on the other hand, spun-laced nonwoven fabric offers better handling and softness and is the most common material for wound care products. Chitosan fabric is chosen for medical functions mostly in nonwoven structures because the nonwoven technology makes prototype production easier and has higher production efficiency and lower cost.

Dyeing and other finishing treatments that involves heating and low pH levels can severely affect the functioning of chitosan textiles. For example, acetic acid is among

the popular additives in the dyeing process, and the dyeing pH environment of some processes can be as low as 4–5, along with heating up to 100°C. The dissolving of chitosan content is likely to occur in such cases. Meanwhile, chitosan can be easily 'overcooked' in finishing processes such as heat setting and loses its functionality. Even if the chitosan material is not affected during the finishing process, unevenness is likely to occur in blending textiles, because chitosan has an extraordinarily stronger absorption ability than most textile materials such as cotton. Therefore, dyeing in the fiber state or printing on fabric is more preferable in most cases.

Chitosan can certainly be coated on ready-made fabrics. In previous studies, researchers have improved the solubility of chitosan by lowering its Mw[19,33] and adding additional chemical groups.[15]From a textile perspective, making chitosan soluble in water would reduce the desired textile functions of the fabric if it is weaved/knitted in the fabric, but soluble chitosan will have strong bio-functions if it is coated on fabric surfaces.

Product development

Fabric is typically not the final product. To achieve functional and nonfunctional goals, a product designer needs to explore the structural possibilities of the product and fabric components. Textiles are commonly used in both fields, but in the product design field, the rich structure and other capabilities are not fully recognized and used. This is partially because of the long chains of textile production and its distance from other types of material such as film, sheets, bars, and other solid forms, but now these chains are shorter and quicker to respond. Designers have more choice for materials and techniques than before. The possibilities are abundant, as even if the fiber material is set, there can be changes in: (a) fiber structure material types; (b) methods of mixing of fiber structure material; (c) yarn structure material types; (d) methods of mixing yarn structure material; (e) yarn-forming methods; (f) parameters in the yarn-forming process; (g) fabric-forming methods: (h) parameters in the fabric-forming process; (i) print and dye methods: and (j) other finishing methods. Compared with normal materials, designers will face more restrictions during the process when dealing with chitosan material (Figure 5). Once the material is settled, selections of materials and manufacturing processes have to be very careful. Some materials or processes that require an acetic environment or high temperature such as coloration, heat setting and bleaching may ruin the performance of chitosan. The designer will also notice that some appearance of the product may not be easy to achieve. For example, the yellowish color and unevenness absorption of dye stuff is difficult to

avoid. In Figure 6, we demonstrate the whole path of textile-related product development that involves chitosan.

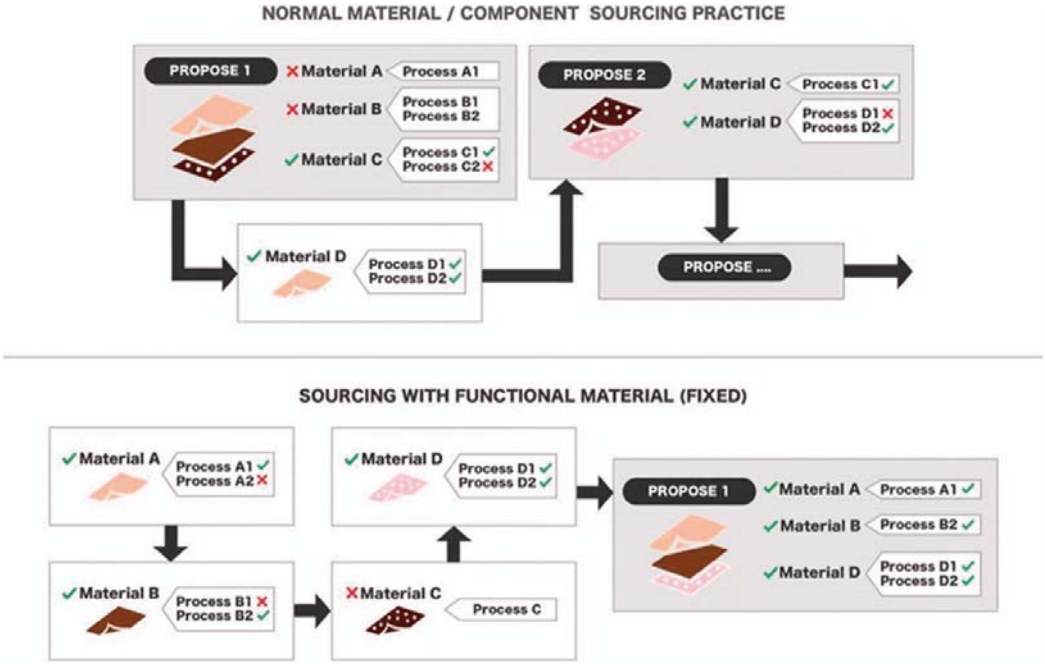

Figure 5. Special path of sourcing with functional materials.

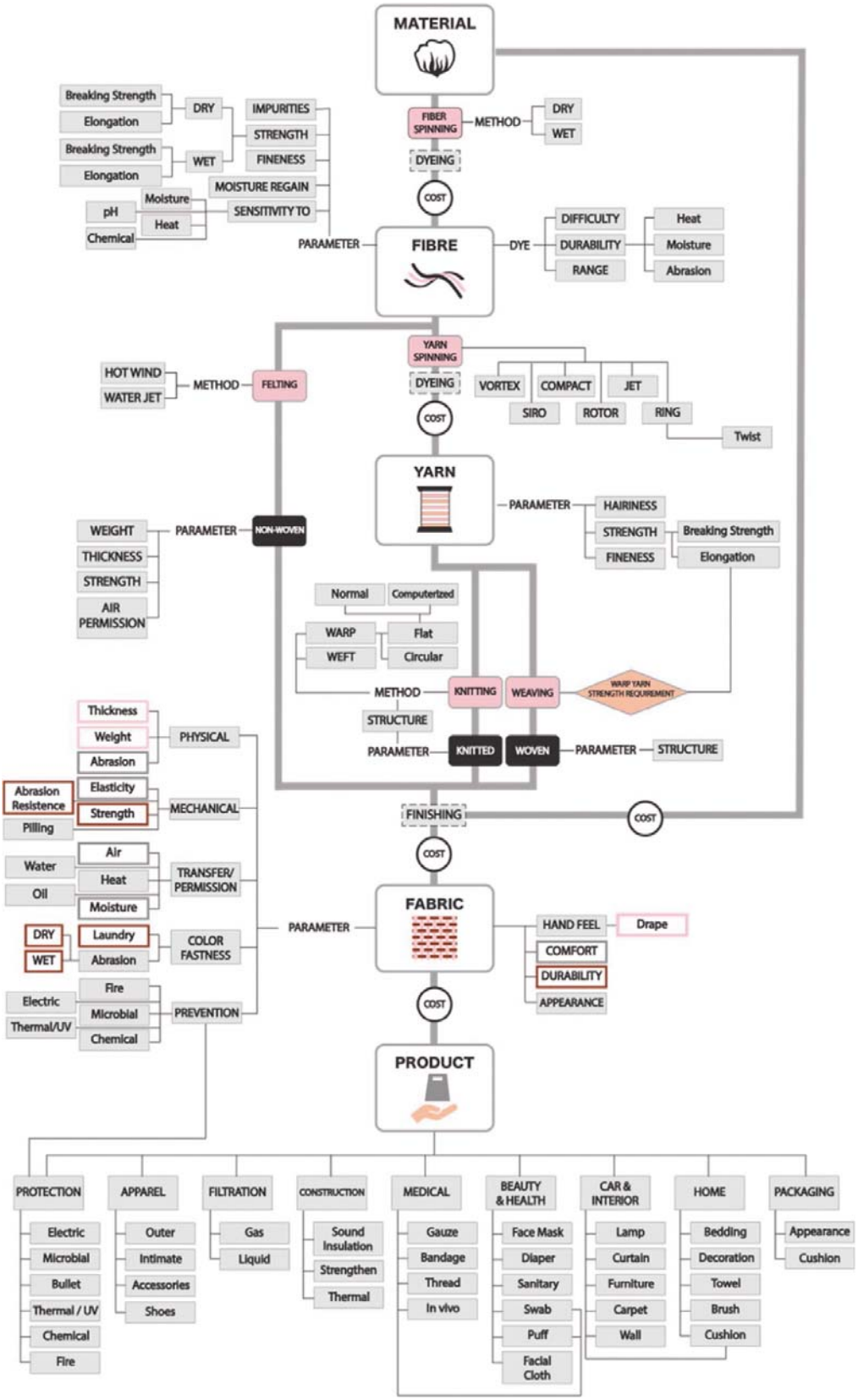

Figure 6. Whole path of textile-related product development that involves chitosan.[7,36–39]

Conventionally, there has been a great need to become ‘consumer centred’ over ‘designer centred’ or ‘expert centred’. To delight clients and users, designers commonly present questionnaires to consumers. However, the results may not be as good as expected by the design team, and the team may not be satisfied by the options ‘approved’ by clients. Thus, an optimal result is not chosen, and the responsibility of an inappropriate selection can be attributed to both parties. The design team often uses images and prototypes that are beautified, and clients have little knowledge about the designer’s reasons to choose one option over another. Clients are confused and bothered by options with few differences. Early and frequent exposure of designs to clients reduces the excitement of seeing new appearances or functions, and managing the expectations of users is crucial.

Prototyping is a common way of communication between designers, users, and producers. However, the research field does not regard them as important. Prototypes are semi-products that demonstrate the appearance or function of the final product to other stakeholders when the parts are not available before or during the design process. They are often created by designers. A well-known function of prototypes is to ensure that the target product in the designer’s head is similar to that in the users’ head and to manage their expectations. In our research, we found that prototypes also clarify direction within the design team, particularly in interdisciplinary design teams. In practice, the development of product structure, plain textiles, and textile finishing may be parallel. It is impractical to wait for textiles ready for prototyping, as production of the plain fabric cost may take most time and is irreversible, thus the later steps are sometimes ‘covering’ the setbacks of the textiles, not mentioning the special properties of textile materials restraining the choice of finishing techniques. Since a crucial success priority of a product is the ‘high quality’ recognized by the end-user, the feasible properties may be more important than functional properties, which are the initial motivation of product development. The path map shown in Figure 6 gives an example of how to check for potential risks of some techniques to the feasible properties recognized by the end-user.

Conclusion

Special properties of chitosan limit the application of this promising material. In this article, special concerns for chitosan application in textile field are discussed, which mainly focus on the need of each stakeholder in the supply chain. The material and fiber selection process involves chitosan-specific key parameter quality monitoring, while the yarn and fabric production preparation process focuses on limitations

caused by mechanical weakness, chemical instability, and static generation. Testing standards and methods are compared, and we find the settling and conduct of methods to be restrained. On one hand, the methods widely used for antibiotics are not suitable for chitosan in solid state, which is the common state in the textile system; on the other hand, the existing textile testing system is chaotic and contradictory. There is a great need to rebuild a qualification for chitosan textiles and other possible natural-material-based textiles with mild functions.

Normal treatment practices such as bleaching, coloration and heat-setting also risk final product performance. Some of the practices affect the ‘quality’ viewed by the consumers, which involves color, hand feel and durability. Once the ‘quality issue’ affects the sales, such a promising material may not have a chance to prove its advantages. On the other hand, designers may, in order to lift the attractiveness of the final product, ask for finishing that harms the core performance and therefore makes the promising material ‘fail’ in the eyes of the consumer. Therefore, in the end, a product development process flow is given marking concerns in each step of production to guide production and sourcing.

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