Sol-Gel Technology

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The commercial availability of inorganic/organic precursors for sol-gel formulations is very high and increases day by day. In textile applications, the precursor-synthesized sol-gels along with functional chemicals can be deposited onto textile fabrics in one step by rolling, padding, dip-coating, spraying or spin coating. By using this technology, it is possible to provide fabrics with functional/multi-functional characteristics including flame retardant, anti-mosquito, water- repellent, oil-repellent, anti-bacterial, anti-wrinkle, ultraviolet (UV) protection and self-cleaning properties. These surface properties are discussed, describing the history, basic chemistry, factors affecting the sol-gel synthesis, progress in sol-gel technology along with various parameters controlling sol-gel technology. Additionally, this review deals with the recent progress of sol-gel technology in textiles in addressing fabric finishing, water repellent textiles, oil/water separation, flame retardant, UV protection and self-cleaning, self-sterilizing, wrinkle resistance, heat storage, photochromic and thermochromic color changes and the improvement of the durability and wear resistance properties.

Keywords: functional finishing ; sol-gel coating ; surface modification ; coating ; protective properties ; oil/water separation ; fabric finishing

1. Introduction

Textile wet processing consists of three important processes, namely pretreatment, coloration (dyeing or printing) and finishing [1][2]. Pretreatment (i.e. scouring, bleaching) is done first to prepare the textiles for the subsequent process called coloration [3][4]. After coloration, the textiles are subjected to the finishing process according to the end-use or consumer requirements [1][2][5][6]. As mentioned, the finishing process is the last chance to provide added value [7]. The finishing process provides special functional properties to the textiles such as flame-retardancy, water-repellency, water-proof, antimicrobial, soil/stain resistance, etc. [8]. Textile finishing can be classified according to different factors based on durability (durable or semi-durable), chemical (wet processing), mechanical (dry or physical treatments such as brushing, shearing, raising), aesthetic (modify the hand/ drape) and functional finishes. Generally, chemical finishing involves the addition of different chemicals based on the intended textile end-use [7]. Among the different finishing techniques, chemical finishing has been widely studied due to the current trends together with the customer requirements for high-tech or high-performance applications [9][10][11][12]. In the past two decades, sol-gel- assisted textile finishing has played a vital role in the development of novel applications to improve the basic properties of textiles. Generally, sol-gel-based textile finishing has more advantages to overcome the shortcomings of conventional finishing techniques [13][14][15][16][17]. The main advantages are eco-friendliness, less chemical utilization, low-temperature treatment, low toxicity to human health, protection of the inherent properties of textile materials, and the possibility to adjust the thickness of the coating and long-lasting properties of finished fabrics. Some types of sol-gel systems also have bacteriostatic or antibacterial effects [16][17][18][19][20][21][22]. These systems are anatase-modified photoactive TiO_2 coatings and sol-gel coatings with colloidal metals or metal compounds embedded in them, such as silver, silver salt, copper compound, zinc or quaternary ammonium salt [18], so sol-gel technology can be applied to textiles to develop various functional finishes with antibacterial [23][24][25][26][27][28][29][30][31][32], water repellent [33][34][35][36][37][38], superhydrophobic [39][40][41][42][43][44], oil/water separations [45][46][47][48][49][50][51][52][53], flame-retardant [54][55][56][57][58][59][60][61][62] multi-functional [63][64][65][66][67][68], ultraviolet (UV) protection [69][70], self-cleaning as well as soil-repellency [18][71][72], photocatalytic [73][74], wear & abrasion resistance properties [75]. The main aim of this review paper is to describe the history, synthesis, application and progress of sol-gel finishing in the textile industry. The various applications of sol-gel techniques in textile finishing are summarized in Figure 1.

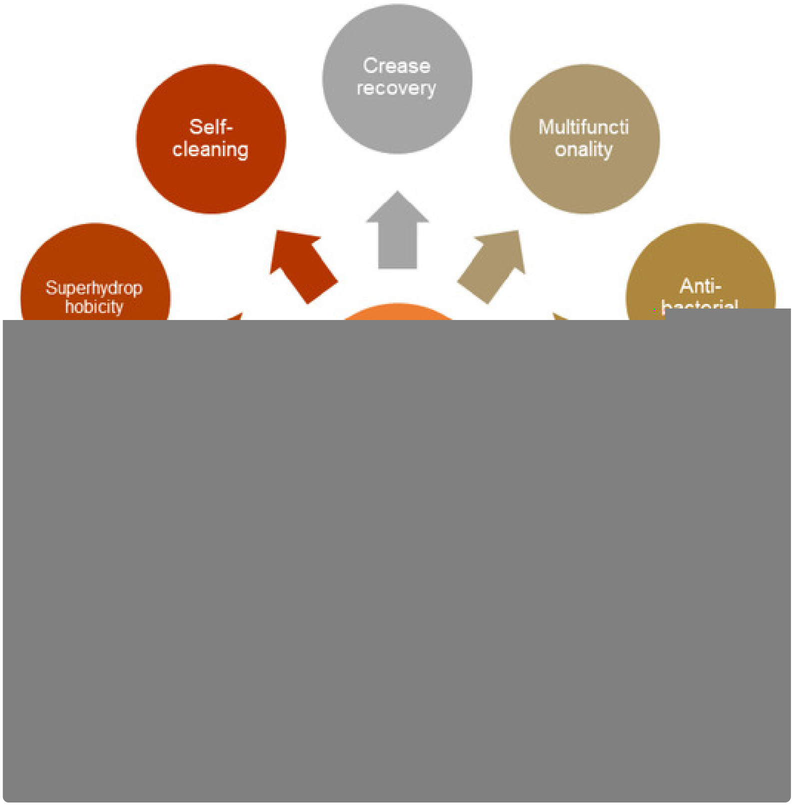

Figure 1. Various applications of sol-gel finishing on textile fabrics.

2. Sol-Gel Technology: History, Chemistry and Synthesis

Sol-gel technology has tremendous potential due to the combination of novel materials with a high degree of homogeneity at the molecular level with excellent physical and chemical properties [76][77]. In ancient times in China, tofu was prepared by utilizing this technology and hence it is not a new technology [78][79]. In the mid-19th century, sol-gel technology was used for preparing one-component compounds using sols and gels [80][81]. In the process of making glass, the sol-gel process requires less temperature compared to the conventional high-temperature melting method [82][83]. The method of forming a gel by mixing $SiCl_4$ and ethanol and hydrolysis in humid air was discovered by Ebelmen in 1846 [84][85]. The sol-gel method was successfully used to produce SiO_2-B_2O_3-$A1_2O_3$-Na_2O-K_2O multi-component glasses which were analyzed by Dislich [86], thus creating great curiosity towards sol-gel technology. In 1981, the first international workshop on glasses [77][79][81][87] and ceramics from gels was held, which helped to further develop sol-gel technology. Sol-gel technology is being used widely since 1980 in the process of synthesizing superconducting materials [88], functional ceramic materials [89], nonlinear optical materials [90], catalysts and enzyme carriers [91][92], porous glass materials and other materials [93][94]. It was a milestone in the history of materials science in which many papers and patents broadly utilizing surface coating and other aspects were published [95][96]. The solution, sol or gel, solidifies the compounds of metal-organic or inorganic (precursor) to form a sol or gel state, followed by the development of an oxide by heat treatment. The polycondensation reaction transforms Si-OR- and Si-OH-comprising species into siloxane compounds which is the basic chemical principle of sol-gel treatment of silica-based materials. Corner sharing connects this to SiO_4 tetrahedra (or $RSiO_3$ tetrahedra in hybrid materials) from a structural point of view. In order to achieve a stable gel, it is essential to maximize the number of siloxane bonds (-Si-O-Si-) and subsequently minimize the number of silanol (Si-OH) and alkoxo (Si-OR) groups [18][97][98][99].

3. Future Trends and Challenges of Sol-Gel Finishing in Textiles

Over a past few decades, the development of innovative multi-disciplinary approaches in textile research and development has brought about unceasing functional changes in the textile and clothing industry. Sol-gel based textile finishing is one among them. The thin-coat finishing of textiles carried out by the sol-gel methods is gaining greater and greater importance owing to its suitability for the versatile functionalization of textiles to impart properties that are difficult and even impossible to obtain with the use of conventional finishing methods. Since the 1960s, sol-gel coating methods for substrates such as metals, glass, and ceramics have been extensively studied. In the past few decades, research on sol-gel technology has focused on making the functionality of textile materials an alternative to conventional textile finishing. The sol-gel technology can improve the water and oil repellency, flame retardancy, UV resistance, antibacterial property and anti-wrinkle properties of textiles, and the method has the characteristics of simple process, excellent functionality, environmental friendliness and long-lasting functionality.

Globally the textile market is mainly dependent on the revolution in high-performance textile products, among them one of the prominent driving forces is sol-gel assisted textile finishing, allowing high-performance textiles to stay ahead of the competition. Market volatility and world-wide competition are the two major factors influencing the textile industry. Henceforth, there arises an urge to boost the ability to produce and merchandize supreme quality and in enriching the products. Even though there are optimistic characteristics features in sol-gel based textile finishing, there are still a lot of items that should be considered. The foremost issue is cost, which has the capacity to limit the expansion of sol-gel based coatings on textiles and mass production. Stated differently, sol-gel coating methods provide functional finished products that seem to be overpriced and require R&D spending in the textile industry. In spite of the fact the long lasting properties of the products finished using these methods are noteworthy, in order to achieve the goal of reaching the common man as well as to a particular community it is expected that the forthcoming technology on textile finishing process must be inexpensive. As a result of the enormous economic potential, besides scientists and researchers, businesses are also attracted to the unique and new properties of sol-gel materials.

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