Survey on Nano-fibers from Acetobacter Xylinum

A. Ashjari, M.E. Yazdanshenas, A. Rashidi, R. Khajiavi, A. Rezaee

Abstract—fibers of pure cellulose can be made from some bacteria such as acetobacter xylinum. Bacterial cellulose fibers are very pure, tens of nm across and about 0.5 micron long. The fibers are very stiff and, although nobody seems to have measured the strength of individual fibers. Their stiffness up to 70 GPa. Fundamental strengths should be at least greater than those of the best commercial polymers, but bulk strength seems to be about the same as that of steel. They can potentially be produced in industrial quantities at greatly lowered cost and water content, and with triple the yield, by a new process. This article presents a critical review of the available information on the bacterial cellulose as a biological nonwoven fabric with special emphasis on its fermentative production and applications. Characteristics of bacterial cellulose biofabric with respect to its structure and physicochemical properties are discussed. Current and potential applications of bacterial cellulose in textile, nonwoven cloth, paper, films, synthetic fiber coating, food, pharmaceutical and other industries are also presented.

Keywords—Microbial cellulose, Biofabric, Microorganisms Acetobacter xylinum, Polysaccharide

I. INTRODUCTION

MICROBIAL cellulose is one of the most promising classes of microbial polysaccharides [1]-[8]. Polysaccharides can be divided according to their morphological localization as: intracellular polysaccharides located inside, or as part of the cytoplasm membrane; cell-wall polysaccharides forming a structural part of the cell wall; and extracellular polysaccharides located outside the cell wall [9], [10]. Extracellular polysaccharides occur in two forms: loose slime, which is non-adherent to the cell and imparts a sticky consistency to bacterial growth on a solid medium or an increased viscosity in a liquid medium; and microcapsules or capsules, which adhere to the cell wall. They have a definite form and boundary, being only slowly extracted in the water or salt solutions. It is therefore possible to separate capsules and microcapsules from loose slime by centrifugation [11], [12]. Exopolysaccharides are long chain polysaccharides consisting of branched, repeating units of sugars or sugar derivatives, mainly glucose, galactose and rhamnose different ratios. They are classified into two groups: homopolysaccharides (cellulose, dextran, mutan, pullulan,curdlan), and heteropolysaccharides (gellan, xanthan) [13],[14].

Cellulose is a linear polymer made of glucose molecules linked by (1→4) glycosidic linkages. There are four principle sources of cellulose. The majority of cellulose is isolated from plants. A second source is the biosynthesis of cellulose by different microorganisms, including bacteria (Gluconacetobacter xylinus), algae, and fungi among others [15]-[19]. The other two less common sources include the enzymatic in vitro synthesis starting from cellulobioseyl fluoride, and the chemosynthesis from glucose by ring-opening polymerization of benzylated and pivaloylated derivatives [20]-[23]. Bacterial cellulose (BC) is produced by strains of the bacterium Gluconacetobacter xylinus, which is a Gram-negative, rod shaped and strictly aerobic bacterium. It has very high purity and contains no lignin, hemicelluloses, pectin, and waxes as plant cellulose does. BC differs from plant cellulose with respect to its high crystallinity, ultrafine network structure, high water absorption capacity, high mechanical strength in the wet state, and availability in an initial wet state and biocompatibility [22], [24]-[26]. Although synthesis of an extracellular gelatinous mat by A. xylinus was reported for the first time in 1886 by A. J. Brown, BC attracted more attention in the second half of the 20th century. Intensive studies on BC synthesis, using A. xylinus as a model bacterium, were started by Hestrin et al. (1947, 1954), who proved that resting and lyophilized Acetobacter cells synthesized cellulose in the presence of glucose and oxygen. Next, Colvin (1957) detected cellulose synthesis in samples containing cell-free extract of A. xylinum, glucose, and ATP. Further milestones in studies on BC synthesis, presented in this review, contributed to the elucidation of mechanisms governing not only the biogenesis of the bacterial polymer, but also that of plants, thus leading to the understanding of one of the most important processes in nature. Acetobacter xylinum produces two forms of cellulose: (i) cellulose I, the ribbon-like polymer, and (ii) cellulose II, the thermodynamically more stable amorphous polymer [27]-[31]. Nanofibrillar structure of bacterial cellulose is responsible for most of its properties such as high tensile strength, higher degree of polymerization and crystallinity index. Bacterial cellulose is used as a diet food and to produce new materials for high performance speaker diaphragms, medical pads [32],[33] and artificial skin [22],[34],[35]. Relatively high cost of the production of cellulose may limit its application to high value-added products as well as specialty chemicals [28],[32]. Significant cost reductions are possible with improvements in fermentation efficiency and economics of scale, the lower limit of the cost of microbial cellulose being determined by the price of the raw material substrates. Consequently, Acetobacter cellulose may always be more expensive to produce than conventional sources of cellulose [36],[37]. For this reason, successful commercialization of Acetobacter cellulose will depend on careful selection of applications where its superior performance can justify its higher cost [34]. The molecular formula of bacterial cellulose (C6H10O5) is the same as that of plant cellulose, but their physical and chemical features are different [38],[39]. Fibers of bacterial cellulose can formed static and agitated cultures.
cellulase is preferred over the plant cellulase at 110°C and exhibits a higher degree of polymerization and crystallinity. It is also capable of being molded into any shape and size. Its synthesis makes it more sustainable as a material for producing high-quality acoustical and crystallinity, and it has a higher degree of polymerization compared to plant-origin cellulase. Its high-quality properties make it more suitable for use in high-temperature applications. A thorough treatment with strong bases at high temperatures allows the removal of non-polymerizable, non-toxic, and fully biocompatible biomaterials.

The thickness of bacterial cellulose from Clostridium cellulolyticum is generally 10 μm, one hundred times thicker than its water holding capacity of 101-3. Therefore, its water holding capacity is over 100 times (by mass) higher than that of other bacterial celluloses [6]. Microbial cellulose is known to be 99-99.5% water-soluble and has a high degree of crystallinity, while plant-origin cellulose is only about 60-70% water-soluble [6]. Microbial cellulose is also known to be 100-1000 times as strong as plant-origin cellulose [6].

The second stage of acetylation involves the production of an acetylated form of the bacterial cellulose solution, which is then mixed with a hydrochloric acid solution to produce a high-temperature, high-quality acoustical material [6]. This material is then subjected to a high-temperature, high-pressure treatment, which results in a high-quality, high-density, and high-strength material [6]. The high-quality acoustical properties of this material make it suitable for use in high-temperature applications [6]. The high-quality acoustical properties of this material make it suitable for use in high-temperature applications [6].
The unique physical and mechanical properties of bacterial cellulose as well as its purity can be exploited for multiple applications that range from high quality audio membranes, electronic paper, and fuel cell to biomedical materials [23],[24].

IV. SOME APPLICATION OF BACTERIAL CELLULOSE

Bacterial cellulose (BC) has long been used in a variety of applications such as diaphragms in speakers and headphones [78-80], papermaking [81], separation membranes [82], and electro-conductive carbon film [83]. Owing to its biocompatibility, BC has also recently attracted a great deal of attention for biomedical applications. For instance, BC has been successfully used as artificial skin for burn or wound healing material [22],[23],[35],[84],[85] artificial blood vessels for microsurgery [86]. The potential of BC scaffold for in vitro and in vivo tissue regeneration also continues to be explored and shows great promise. To broaden the biomedical applications of BC, various attempts have been made to produce BC composites with high functionality [19],[39]. Among them, BC/PEG composite is one of candidates that have great potential applications for tissue engineering and drug delivery. Bacterial cellulose to adsorb metal ions has been reported in the many previous studies [86].

In the biomedical area, bacterial cellulose can be used for wound healing applications 18, micro vessel endoprosthesis[23], scaffolds for tissue engineered cartilage [47] and tissue engineered blood vessels [86]. Some of the materials based on bacterial cellulose, such as new skin substitutes and wound dressing materials, are now commercially available [23]. Other biomedical applications such as the use of bacterial cellulose as a regenerative aid to correct skeletal defects are under investigation.

Bacterial cellulose has been found to be attractive as a novel scaffold material due to its unique material properties. Porosity is the most important morphological parameter in the design of scaffolds for tissue engineering. Fabricating a scaffold with the desired pore size and porosity is of great importance in tissue engineering [87]. For bacterial cellulose scaffold, the definition of a specific pore size in a bacterial cellulose fibrous hydro gel is not relevant because the nanofibers can be pushed aside by migrating cells. Bacterial cellulose has potentialities to be an appropriate scaffold for different types of tissue and organ[17].

Addition of cellulose nanofibers obtained by acid hydrolysis of cellulose fibers at low concentrations to polymer gels and films as reinforcing agents showed significant changes in tensile strength and mechanical properties [53]. Based on the tensile strength, low oxygen transmission (barrier property) rate and its hydrophilic nature, the processed cellulose membrane appears to be of great relevance for its application as packaging material in food packaging, where continuous moisture removal and minimal oxygen transmission properties play a vital role [69]. The unique physical and mechanical properties of microbial cellulose such as high reflectivity, flexibility, light mass and ease of portability, wide viewing angles, and its purity and uniformity determine the applications in the electronic paper display [79]. Fragmented bacterial cellulose has promising prospects in papermaking, so test pieces of flexure-durable papers and high filler-content papers, which are ideal for banknote paper and bible paper, are being prepared [88],[89].

V. CONCLUSION

Microbial cellulose has proven to be a remarkably versatile biomaterial and can be used in a wide variety of fields, to produce for instance paper products, electronics, acoustics, and biomedical devices. Various biodegradable and biocompatible polymeric materials have recently been investigated to fabricate inorganic-organic hybrid composites by mimicking the mineralization system of natural bone, with some successful outcomes. However, the search for an ideal biomaterial with properties and functionalities similar to natural bone is a continuing process because no single material can satisfy all the requirements for creating optimal scaffolding properties, such as strength, toughness, osteoconductivity, osteoinductivity, controlled degradation, inflammatory response, and deformability. In this study, the ultrafine 3-D BC network structure with its native unique properties is exploited for the synthesis of materials analogous to natural bone. Our study showed that the formation of apatite is dependent on the presence and type of surface functional groups in the microfibrillar BC network.

Among new commercial applications, BC has been shown to be very beneficial in the treatment of secondary and third degree burns. A clinical study has been performed on 34 patients. The BC wound dressing materials were directly applied on the fresh burn covering up to 9-18% of the body surface. The following diagnoses were considered: macroscopic observation of the wound and wound extract, epidermis growth, microbiological tests, and histopathological studies. BC appears to be one of the best materials to promote wound healing from burns. Factors for this success include but are not limited to the following: a moist environment for tissue regeneration; significant pain reduction; specific cellulose nano-morphology which promotes cell interaction and tissue re-growth; significant reduction of scar tissue formation; and, easy and safe release of wound care materials from the burn site during treatment. Microbial cellulose promises to have many new applications in wound care that extend beyond burn applications including, but not limited to, the following: surgical wounds, bedsores, ulcers, tissue, biotextile, biological nonwoven fabric and organ engineering.

REFERENCES
