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Polysaccharide Polyelectrolyte Complexation: An Engineering Strategy for the Development of Commercially Viable Sustainable Materials

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Abstract : Sustainable and environmentally compatible materials are needed for a wide variety of volume commercial applications. Current synthetic materials such as plastics, fluorochemicals (such as PFAS), adhesives and resins in form of sheets, laminates, coatings, foams, fibers, molded parts and composites are used for countless products such as packaging, food handling, textiles, biomedical, construction, automotive and general consumer devices. Synthetic materials offer distinct performance advantages including stability, durability and low cost. These attributes are associated with the physical and chemical properties of these materials that, once formed, can be resistant to water, oils, solvents, harsh chemicals, salt, temperature, impact, wear and microbial degradation. These advantages become disadvantages when considering the end of life of these products which generate significant land and water pollution when disposed of and few are recycled. Agriculturally and biologically derived polymers offer the potential of remediating these environmental and life-cycle difficulties, but face numerous challenges including feedstock supply, scalability, performance and cost. Such polymers include microbial biopolymers like polyhydroxyalkanoates and polyhydroxbutirate; polymers produced using biomonomer chemical synthesis like polylactic acid; proteins like soy, collagen and casein; lipids like waxes; and polysaccharides like cellulose and starch. Although these materials, and combinations thereof, exhibit the potential for meeting some of the performance needs of various commercial applications, only cellulose and starch have both the production feedstock volume and cost to compete with petroleum derived materials. Over 430 million tons of plastic is produced each year and plastics like low density polyethylene cost ~$1500 to $1800 per ton. Over 400 million tons of cellulose and over 100 million tons of starch are produced each year at a volume cost as low as ~$500 to $1000 per ton with the capability of increased production. Cellulose and starches, however, are hydroscopic materials that do not exhibit the needed performance in most applications. Celluloses and starches can be chemically modified to contain positive and negative surface charges and such modified versions of these are used in papermaking, foods and cosmetics. Although these modified polysaccharides exhibit the same performance limitations, recent research has shown that composite materials comprised of cationic and anionic polysaccharides in polyelectrolyte complexation exhibit significantly improved performance including stability in diverse environments. Moreover, starches with added plasticizers can exhibit thermoplasticity, presenting the possibility of improved thermoplastic starches when comprised of starches in polyelectrolyte complexation. In this work, the potential for numerous volume commercial products based on polysaccharide polyelectrolyte complexes (PPCs) will be discussed, including the engineering design strategy used to develop them. Research results will be detailed including the development and demonstration of starch PPC compositions for paper coatings to replace PFAS; adhesives; foams for packaging, insulation and biomedical applications; and thermoplastic starches.

Keywords : biomaterials engineering, commercial materials, polysaccharides, sustainable materials
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