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Rheology and extrusion of Lyocell towards additive manufacturing of regenerated cellulose

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Abstract

Applications of renewable and biodegradable sources are now intensely investigated for the preparation of higher valued products due to the environmental concerns regarding petroleum-based polymers and composites. Cellulose is the most abundant natural polymer on earth. Its use is limited due to its poor processability. Commonly, regenerated cellulose for various applications, such as Rayon, is produced with very environmentally harsh polluting chemicals. An eco-friendlier solution is the use of N-methylmorpholine-N-oxide (NMMO)/water system as a viable alternative due to the non-toxic nature of NMMO. Furthermore, NMMO can be completely recycled. Regenerated cellulose from NMMO/water systems is trademarked as Lyocell. In comparison to other regenerated cellulose productions, the production of Lyocell consumes less water and energy. Additive manufacturing of Lyocell has numerous potential applications in the biomedical, environmental, and structural industries. 3D printing of Lyocell using an Extrusion-Based Additive Manufacturing (EBAM) system is economically viable; however, it requires fundamental understanding and proper control over the process parameters. In this work, we explore the feasibility of using Lyocell as an alternative material for future large-scale EBAM parts and systems. The methodology includes the detailed characterization and preparation of the Lyocell dope and its challenges, including manufacturing set-up, repeatability, and feasibility of scalability. For this, we characterized and studied the rheology of the Lyocell-regenerated cellulose with 12% wt. of cellulose content. This study focused on the rheology characterization of the dope in steady shear and oscillation conditions. The characterization was done for different dope moisture contents defined by evaporation time during fabrication and rheology behavior at different temperatures (70, 80, 90°C). The results are then related to the extrusion of Lyocell and a study of the flow rate and swelling of the extrudate at the die. Finally, we relate these results to the implications of these on future EBAM systems, such as layer adhesion and dimensional stability.