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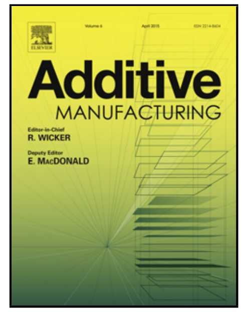

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Rheological Behavior of PDMS Silicone Rubber for 3D Printing of Medical Implants

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Abstract:

The diagnosis and treatment of patients suffering from neurological diseases with patient-individualized silicone rubber-based implants is one of the most promising and challenging approaches to improve treatment outcome. Therefore, medical additive manufacturing techniques are developed for fabrication of such implants, but currently do not achieve the required printing resolution. This is caused by intensive droplet spreading of the initially liquid silicone rubber on the printing substrate. While empirical optimization approaches for the droplet spreading are intensive in cost and time, we develop a mathematical optimization approach to calculate the optimal printing parameters for minimal droplet spreading. Since the viscosity profile of thermal curing silicone rubber is the main reason for the droplet spreading, we implemented a rheology model for calculation of the optimal heat curing parameters. A Dual-Arrhenius equation was used to correlate the temperature-time-profile of the curing process with the curing-related viscosity rise and the temperature-related viscosity fall of the liquid silicone rubber. Two commonly used silicone rubbers were characterized with a rheometer at different isothermal and anisothermal curing profiles. High correlation between the calculated and the measured viscosity profiles were observed, giving the ability to optimize the curing process parameters to the rheological behaviour of the used silicone rubber.

Keywords: 3D printing, droplet spreading, rheology model, silicone rubber printing, customized neural implants, PDMS

1 Introduction

Recently, medical additive manufacturing of personalized and individualized implants has become a major field in additive manufacturing. Several additive manufacturing techniques were developed to fabricate e.g. individualized blood vessels [1], bandages [2], bones [3], dental prosthesis [4], molds for cranial plates [5], tissue and organs [6] made from different materials like photosensitive polymers [7], thermoplastic polymers [8] or metal materials [9]. Although it was shown that all of these techniques can be used for a wide range of experimental applications, only 3D printing of titan-based orthopedic implants was approved for long-term clinical application. 3D printing methods for long-term used polymer implants are, so far not approved. Consequently, patients suffering from neurological pathologies such as epilepsy, Parkinson's disease or sensorineural hearing loss, which will be typically treated with standard-sized electrocortical grid array, deep brain stimulation electrodes or cochlear implant electrodes, cannot benefit from the advantages of patient individualized polymer implants. To address this gap, a 3D printing method for these typical silicone rubber-based neural implants needs to be developed. Therefore, we presented a layer by layer 3D printing process [10] for individually shaped silicone rubber-based neural implants.

Since these standard "medical grade" silicone rubbers are thermal-curing polymeric liquids, which spread on solid surfaces after droplet deposition, an infrared high-speed-curing system was used to heat up the printed silicone rubber instantly and thereby to cure the initially viscous silicone rubber material before it spreads out during the curing process. It was shown [10], that spreading of large silicone rubbers droplets (radii > 1 mm) can be effectively reduced to less than 5 % of the droplet spreading at room temperature. But since the typical neural implant dimensions are less than 0.6 mm, much lower droplet size is required to print these implants. Therefore, further optimization of the printing resolution and minimal producible structure width of the printing system are required.

It is known that reduction of the droplet spreading can be easily achieved by increasing the viscosity or the cross-linking speed of the silicone rubber [10]. Therefore, different material parameters have been identified to adjust the viscosity or the curing speed e.g. amount of fumed silica filler [11,12], chain length of the polymer [13,14], and amount of crosslinker [14]. However, such material modifications cannot be easily applied to "medical grade" silicone rubbers since this would