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Development of a viscosity model for a silicone rubber 3D printing process

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Medical rapid prototyping of individualized implants has become a major field in additive manufacturing. Several rapid prototyping techniques were developed to fabricate e.g. individualized bones and orthopaedic implants. Although these techniques can be used for a wide range of experimental applications, no printing technique is available for silicone-rubber-based neural implants e.g. cochlear implant electrodes or electrocortical grid. To close this gap, we presented a silicone rubber 3D printing process.

Since the standard “medical grade” silicone rubber are thermal-curing liquids, an infrared high-speed-curing system was used which heats up the printed silicone rubber instantly and thereby cures the initially viscous silicone rubber material before it spreads out during the curing process. To optimize the fabrication accuracy and resolution of this system, a time-temperature profile for the curing process should be evaluated, where the spreading of the silicone rubber material is minimal. Therefore, further knowledge about the curing mechanisms and the rheological behavior of the silicone rubber is mandatory. As the spreading dynamics of polymeric liquids depends mainly on the viscosity of the polymeric liquid, a rheology model was developed which correlates the infrared heat-related temperature-time profile with the curing-related viscosity rise and the temperature related viscosity fall.

Two commonly used silicone rubbers (Silpuran 2430 and 2440, Wacker Chemie AG) were characterized with a vulcameter at different isothermal temperatures (35°C - 70°C). Their isothermal viscosity curves were correlated to their temperature-time profiles via an empirical viscosity expression by using a two-stage Arrhenius equation. To cope with a realistic nonisothermal curing process, a time-temperature integral for the degree of cure was introduced into the isothermal model and tested at different heat rates (5 K/min - 60 K/min).

Good correlations were observed, giving the ability to optimize the curing conditions of the curing process to the rheological behavior of the used silicone rubber.

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Direct acoustic stimulation with the codacs™

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Currently available conventional hearing aids often do not provide sufficient benefit to patients with severe-to-profound mixed hearing losses (MHL). The new implantable hearing system Codacs™ was designed to close the treatment gap between active middle ear implants and cochlear implants in cases of severe-to-profound mixed hearing loss. The so called Direct Acoustic Cochlea Implant (DACI) uses a piston prosthesis in a stapedotomy that directly provides acoustic input to the perilymph. Comparison of outcomes with Cochlea Implant (CI) recipients demonstrate that for patients with sufficient cochlear reserve speech intelligibility in noise is significantly better with the Codacs™ than with a CI (Kludt et al., 2016). On the other hand, results with conventional hearing aids show less benefit than what can be obtained under optimal conditions (PBmax, Hoppe et al., 2016). Here our results indicate that the benefit is significantly better in Codacs™ patients than with conventional hearing aids. Reports that the Maximum Power Output (MPO) of the Codacs™ covers the residual dynamic range even in severe hearing loss patients (Zwartenkot et al., 2014) and own experimental and clinical results support these findings. Furthermore long term analysis up to 5 years gives no indication for an accelerated presbycusis by direct stimulation.

Our results indicate that for patients with sufficient cochlear reserve, speech intelligibility in noise is significantly better with the Codacs™ than with a CI. On the other side Codacs™ results are close to what can be obtained under optimal conditions (PBmax) and there are no indications for negative long term effects.