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Tailoring the mechanical properties of the implantable polyurethanes by variation in the chain structures

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The fatigue performance of biocompatible elastomers tested in physiological conditions is the main criterium to optimize efficiently the composition design of new materials as well as to evaluate commercial biomaterials for orthopedic applications [1,2]. Soft polyurethane elastomers, primarily polycarbonate-urethanes (PCU), have significant advantages as a basis to fabricate biostable soft orthopedic devices of a new generation [3-5]. On the one hand softer materials mimics the natural tissue properties, on the other hand they should be elastic enough to avoid irreversible mechanical deformations under long-term physiological loadings. A combination of MDI-based polycarbonate urethane core surrounded with long polydimethylsiloxane (PDMS) chains could be promising to solve this problem and simultaneously reduce the fluid adsorption of a core material.

The sensitivity of the urethane-based polymers to their environment has been tested on two commercially available as well as on ten novel thermoplastic elastomeric biomaterials synthesized in our laboratory. The chain structure of these PU-based biomaterials is shown in Fig.1. To provide a wide array of mechanical properties (elastic moduli, stress-strain behavior), soft segment (SS) chemistry, structural variations in multiblock PDMS-polycarbonate copolymer chains via regulated distance between SS-blocks as well as hard segment content have been systematically varied. The structure and molecular weight of the synthesized samples before and after specimen processing (i.e. drying, annealing, cleaning) were controlled using FTIR, DSC, GPC and viscometric methods.

To examine stress-life behavior of potential polyurethane-based meniscus implants, several sets of viscoelastic test specimens were molded in a cylindrical or disk geometry of 13 or 40 mm diameter and 6 or 4 mm thickness correspondently (Fig.2). The fatigue resistance of the test specimens have been studied using tensile as well as compression cyclic loading. In addition to these studies, several specialized tests on the new urethane elastomers have been conducted under simulated physiological compressive loading (1200 N), temperature (37 ^{o}C) and liquid environment for knee spacer applications. Elastic moduli for all materials range from 8 MPa to 16 MPa (Hardness 70-80 A Shore). A lack of thermo-mechanical transitions near the body temperature was confirmed using dynamic mechanical analysis (DMA). All materials were in a viscoelastic state over the temperature range tested up to 45 ^{o}C and demonstrated the modulus softening at the body temperature.

Dynamic compression screening up to 80% deformation of the specimens was utilized to evaluate an elastic range and define a compressive deformation at 1200N. The fatigue behavior of each material was investigated under cyclic compression in a linear elastic range (at 20% of deformation) as well as under physiological loading (1200N) with corresponding compressive deformation 40-50%. The comparison of fatigue responses between novel synthetic meniscal analogs with systematically varied structure improves the understanding of the structure-mechanical response relationship to develop the most promising materials.

Figure1: Components and chain structure of thermoplastic PCU-PDMS-based biomaterials. Conditions: multistep synthesis over the catalyst-free condition using in-line FTIR-control.
Figure 2: From synthesis to test specimens. Extrusion and injection molding techniques are used for processing

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Abb. 1

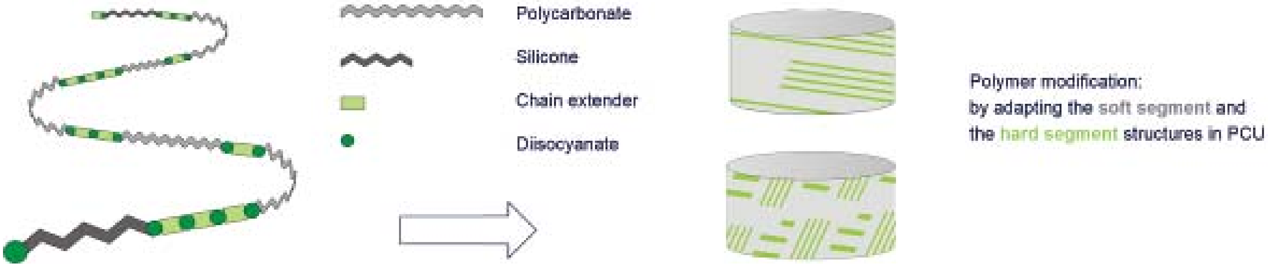
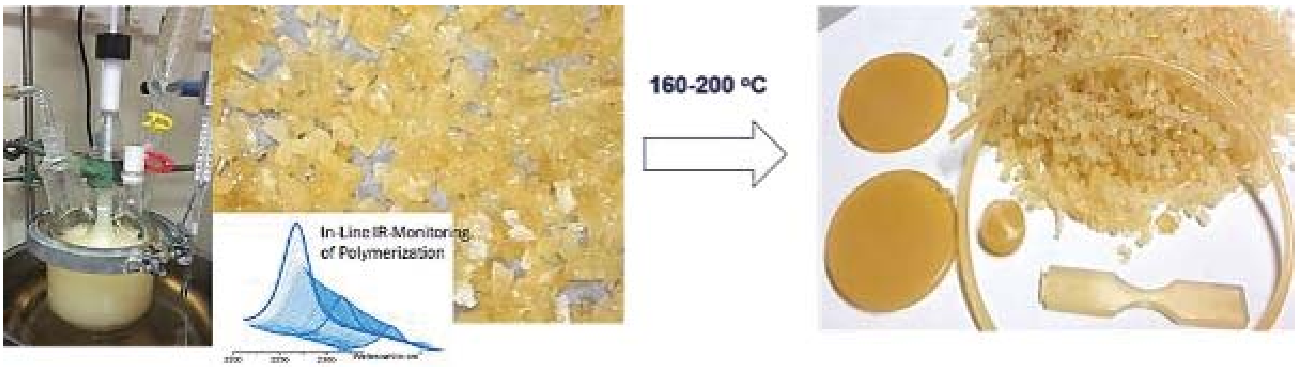

Polycarbonate
Silicone
Chain extender
Diisocyanate
Polymer modification:
by adapting the soft segment and
the hard segment structures in PCU

Abb. 2


In-Line IR-Monitoring
of Polymerization
160-200 °C