BIOSTABLE POLYURETHANE MATERIALS FOR CHONDRAL IMPLANTS: IN-SITU MONITORING OF URETHANE POLYMERIZATION

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MOTIVATION

Thermoplastic polycarbonate-urethane (TPCU) elastomers are currently attracting great interest as a promising basic matrix for fabricating the next generation of biostable, implantable biomedical devices [1-3].

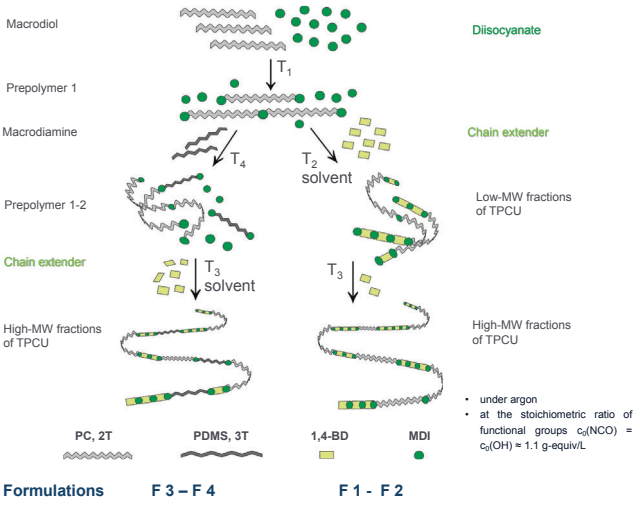
Segmented polyurethane block co-polymer elastomer chains consist of alternate soft and hard segments. Variations in block lengths, polarity and connecting (coupling) order of the hard and soft segments in a polymer chain lead to different chemical compatibility between the structural elements and introduce wide changes in block-co-polymer morphology, thermo-mechanical behavior as well as hydrolytic stability and biocompatibility of the potential medical materials [4-5].

Hence it is extremely important to control co-polymer formation and segmental constitution during synthesis. Undefined variations in the synthesis protocol of high molecular TPCU block-copolymers will strongly affect the molecular structure of the polymer chains as well as their molecular weight distribution in step-growth polyaddition of diols and diisocyanates.

The goal of this project was to develop catalyst-free, multi step synthesis procedures for optimizing the large scale production of medical-grade TPCU elastomers with controlled molecular structure and physical-mechanical properties.

SYNTHETIC DESIGN OF PC-PDMS-MDI-BD BLOCK COPOLYMERS

to have *soft, elastic, biostable, processable medical grade polyurethane materials*

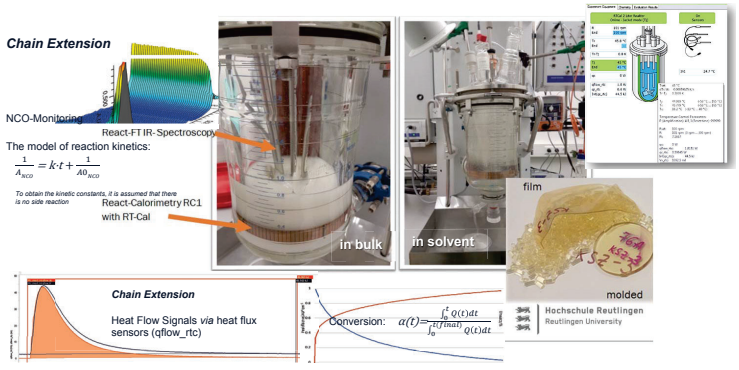


- under argon
- at the stoichiometric ratio of functional groups $c_0(NCO) = c_0(OH) \approx 1.1$ g-equiv/L

Formulations F 3 – F 4 F 1 - F 2

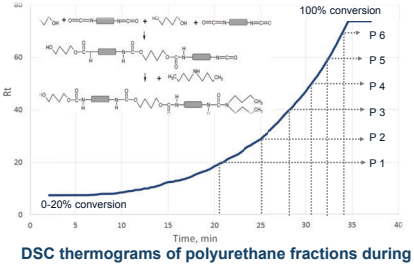
❖The multi-step procedure gives good control of polymer architecture in catalyst free systems
❖The prepolymer formation (endcapping the macrodiol) was carried out in bulk, while the chain extending the oligomers with a low molecular weight diol took place in solvent.

EXPERIMENTAL SETUP OF THE REAL-TIME MONITORING POLYURETHANE FORMATION IN CATALYST FREE SYSTEM



RESULTS

Rheological profiles of chain extending the prepolymers in solvent (DMAc) at 50 °C

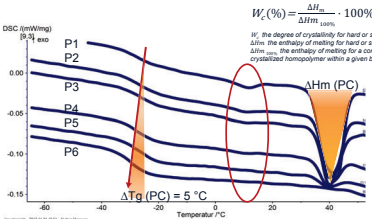


for TPCUs (F 1 - 2): $M_{[\eta]} \approx 51 - 53$ T (after extrusion)

for TPCSiUs (F 3 - 4): $M_{[\eta]} \approx 46 - 49$ T (after extrusion)

M_n (GPC) ≈ 50 T, M_w (GPC) ≈ 100 T

DSC thermograms of polyurethane fractions during chain extending the prepolymers



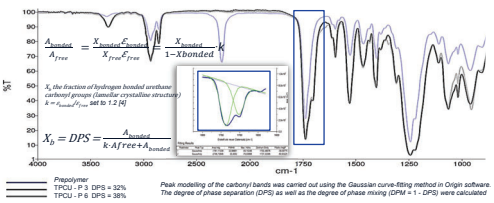
$$W_c(\%) = \frac{\Delta H_m}{\Delta H m_{100\%}} \cdot 100\%$$

W_c the degree of crystallinity for hard or soft phase (%)
ΔHm the enthalpy of melting for hard or soft phase (J/g)
$\Delta Hm_{100\%}$ the enthalpy of melting for a completely crystallized homopolymer within a given block (J/g)

Degree of crystallinity (W_c) of soft and hard segments in TPCU-fractions (F1_2.0, ω(HS) = 28%)

Polymer fraction in copolymer	ΔHm_{SS}, J/g	$W_{c\,SS}$, %	ΔHm_{HS}, J/g	$W_{c\,HS}$, %
P 1	11.4	20	5.1	21
P 2	6.4	11	5.1	21
P 3	5.9	10	5.1	21
P 4	2.6	5	5.2	22
P 5	0.5	1	5.4	23
P 6	0	0	5.6	24
Homopolymer PC (M_w = 2T) MDI-BD	57.3	100	23.9	100

FTIR profiles of polyurethane fractions during chain extending the prepolymers. Analysis of carbonyl region



$$\frac{A_{bonded}}{A_{free}} = \frac{X_{bonded}}{X_{free}} \cdot \frac{\varepsilon_{bonded}}{\varepsilon_{free}} = \frac{X_{bonded}}{1 - X_{bonded}} \cdot k$$

X_b the fraction of hydrogen bonded urethane carbonyl groups (lamellar crystalline structure)
$k = \varepsilon_{bonded}/\varepsilon_{free}$ set to 1.2 [4]

$$X_b = DPS = \frac{A_{bonded}}{k \cdot A_{free} + A_{bonded}}$$

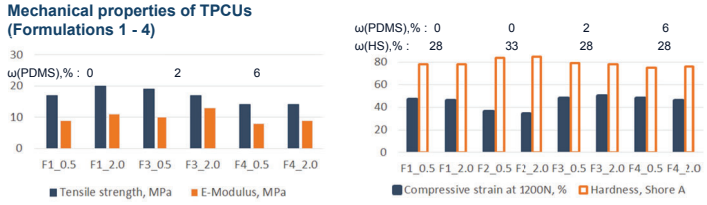
Peak modelling of the carbonyl bands was carried out using the Gaussian curve-fitting method in Origin software. The degree of phase separation (DPS) as well as the degree of phase mixing (DPM = 1 - DPS) were calculated

Degree of crystallinity (W_c) and phase separation (*DPS*) in TPCUs

Formulation	$W_{c\,HS}$, %	*DPS*, %
F 1_2.0**	28	38
Bionate-80A	29	40
F 3_0.5	27	34
F 3_2.0	28	35
F 4_0.5	25	34
F 4_2.0	25	33

- the 0.5 or 2.0 L reactor experiments
- commercially available Carbothane-85A (DPS = 34%)

Mechanical properties of TPCUs (Formulations 1 - 4)



CONCLUSIONS

- ✓ A series of the biomedical TPCUs with different percentages of hard segment and a silicone component in the soft segment were synthesized in a multi-stage one-pot method.
- ✓ The kinetic profiles of the urethane formation in polycarbonate-silicone-urethane-urea-block copolymer systems were monitored by rheological, in line FTIR ATR spectroscopic (React IR) and real-time calorimetric (RC1) methods.
- ✓ The low molecular weight fractions (P1-P6) were characterized off-line via spectroscopic and thermoanalytical methods. FTIR and DSC methods were used for qualitative and quantitative evaluation of the degree of crystallinity for hard and soft phases in TPCUs. A variety of degree of phase separation can be explained with different volumes of HS-domains and their distribution within a soft matrix, while a crystallinity of HS-phase can be affected by density of hydrogen bonds within molecular packing.
- ✓ Mechanic response of the elastomer end-products to compression and tensile loading were systematically studied for controlling the reaction reproducibility. Tensile strength, hardness and compressive strains of the synthesized elastomers were highly dependent on the TPCU composition, but not significantly affected by choiced up-scaling strategy.
- ✓ Optimization of reaction parameters (concentration, flow rate of reagent addition, mixing rate, reaction temperature and time) allowed to produce the polyurethane chains with well-controlled structure und distribution of HS length. A new synthesis protocol made it possible to reproducible manufacture up to 1kg of the compositionally homogenous elastomer biomaterial.

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