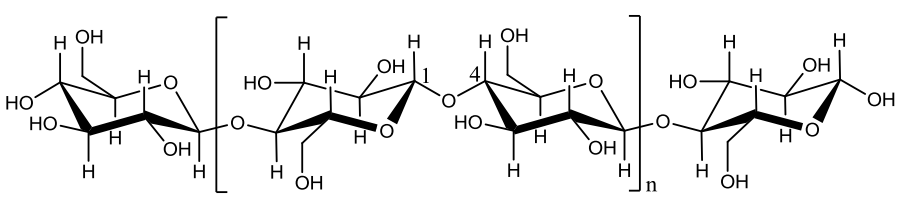
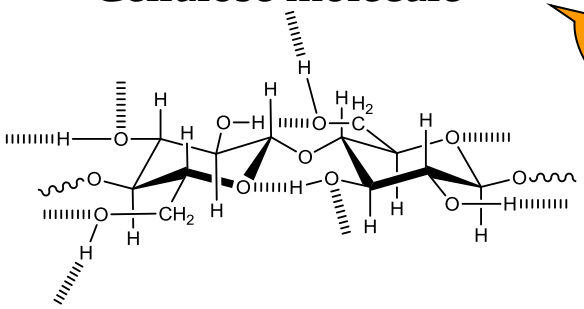
Rigid Polyurethane Foam/Cellulose Whiskers Nanocomposites: Preparation, Characterization and Properties

Cellulose structure and characteristics

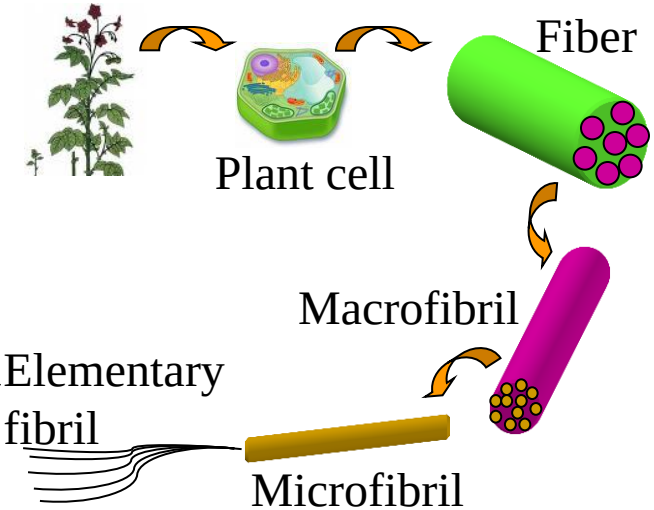
- Polymeric chains of β-(1,4)-D-glucose units
- Abundance - Annual biomass production of 1.5×10^{12} tons
- Renewability - Environment biocompatible products



Cellulose molecule

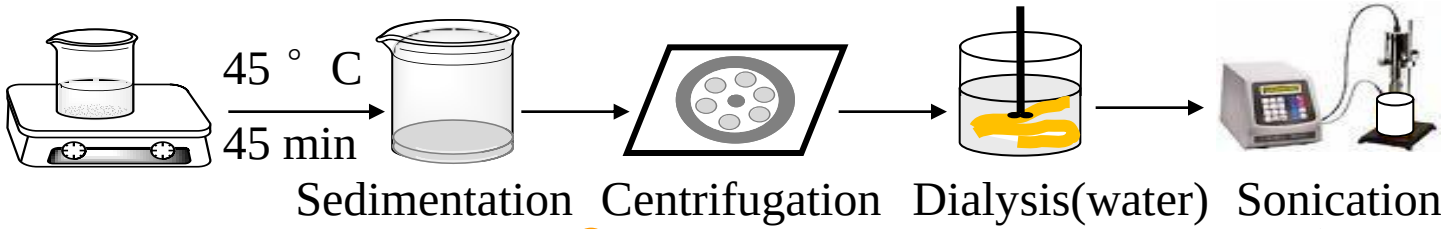


Inter- and intra-molecule hydrogen bonding

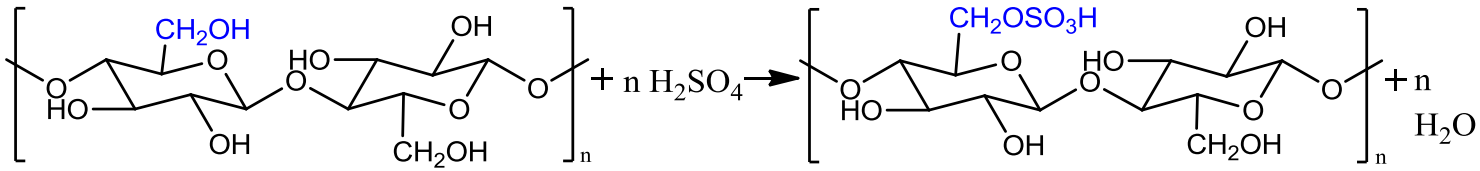


Preparation of cellulose whiskers

- Under certain acid hydrolysis conditions, transverse cleavage happens along the amorphous regions and releases needle-like monocrystals, which refer to whiskers.

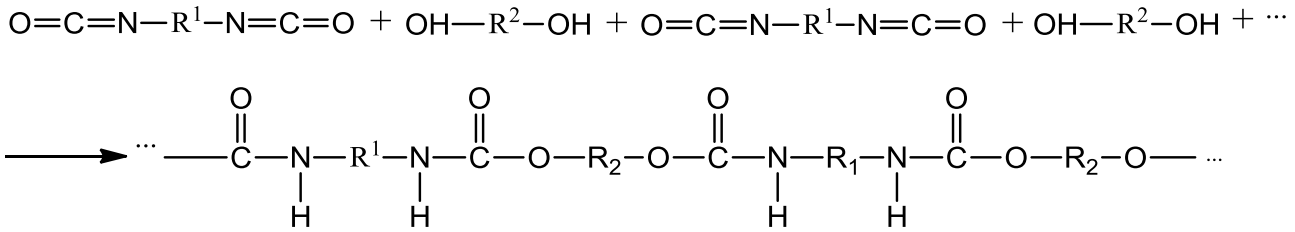


10-20 nm in diameter
100-200 nm in length
Bending strength ~10 GPa
Elastic modulus ~143 GPa



Polyurethane structure

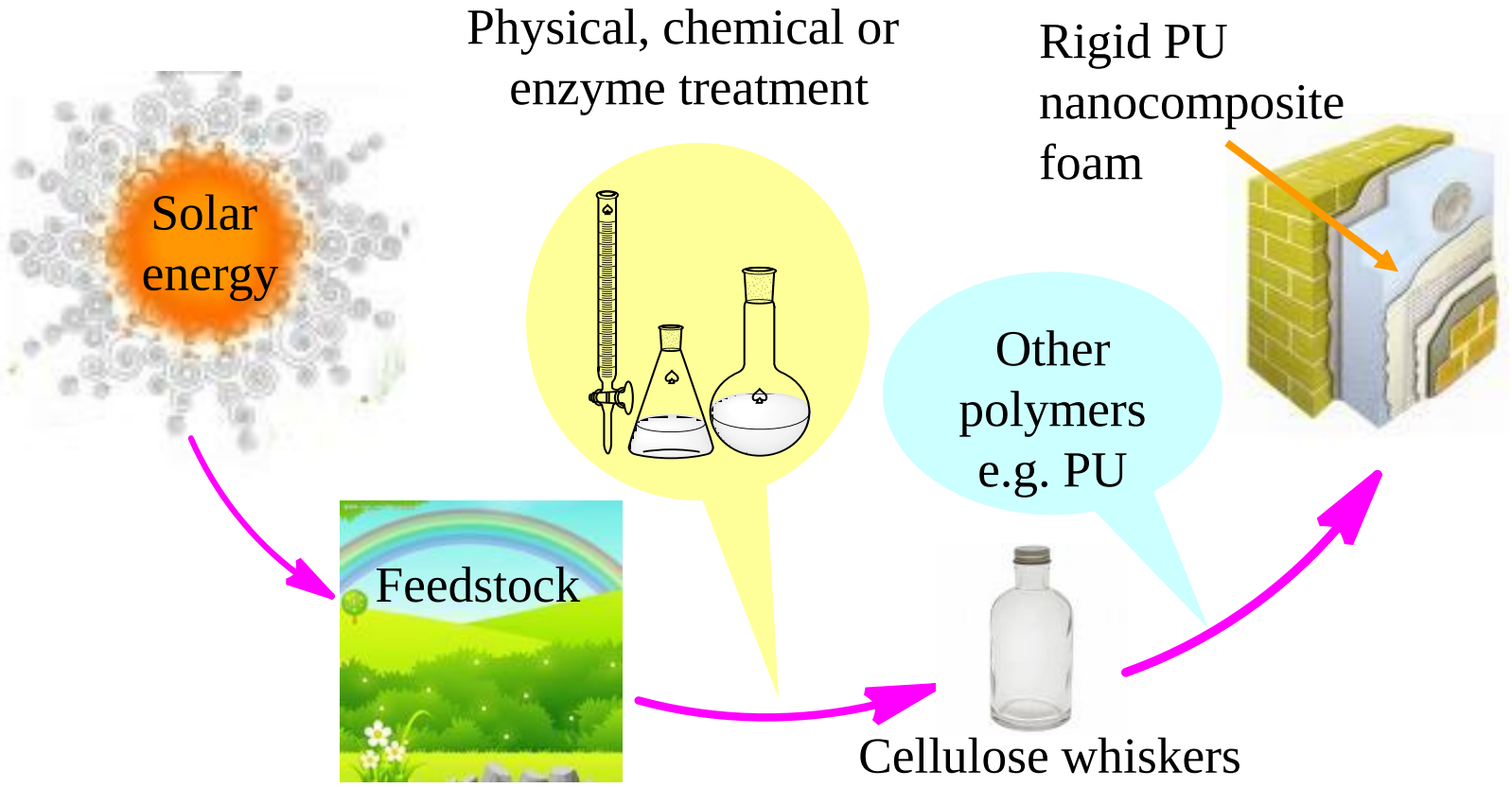
- Polyurethane (PU) is any polymer consisting of a chain of organic units joined by urethane links.
- Rigid PU foam is a highly crosslinking polymer with a closed-cell structure.



Strong but with
Significantly lower density
Dimensional stability
Thermal insulation
Good adhesive properties
Impervious to moisture
Low cost

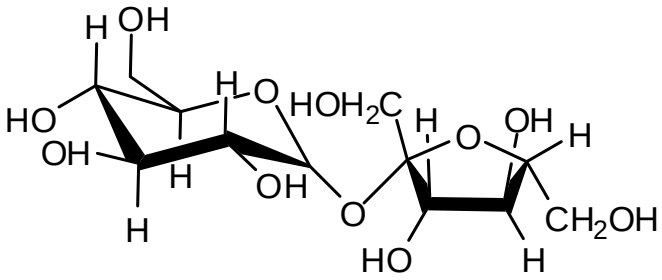
But not as stiff as traditional materials

Objective-improve mechanical properties

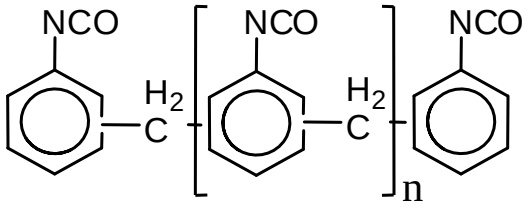


Reagents

Sucrose-based polyol (S polyol), F = 4.4
Glycerol-based polyol (G polyol), F = 3
Polymeric methylene diphenyl diisocyanate (MDI), F = 2.7
Dimethylcyclohexylamine (DMCHA)
Potassium octotate
Silicon surfactant
n-pentane (boiling point 36.1° C)

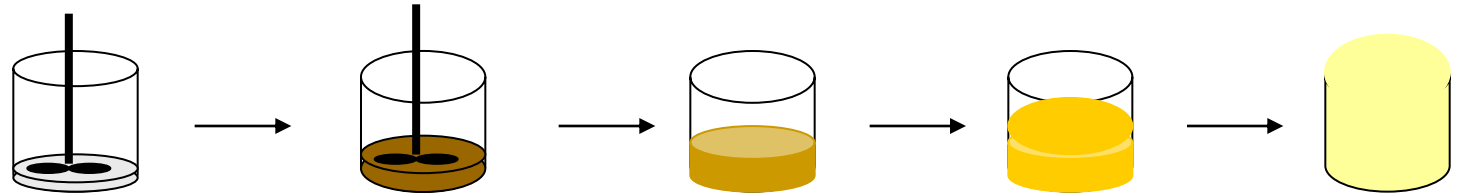


Sucrose



Polymeric MDI

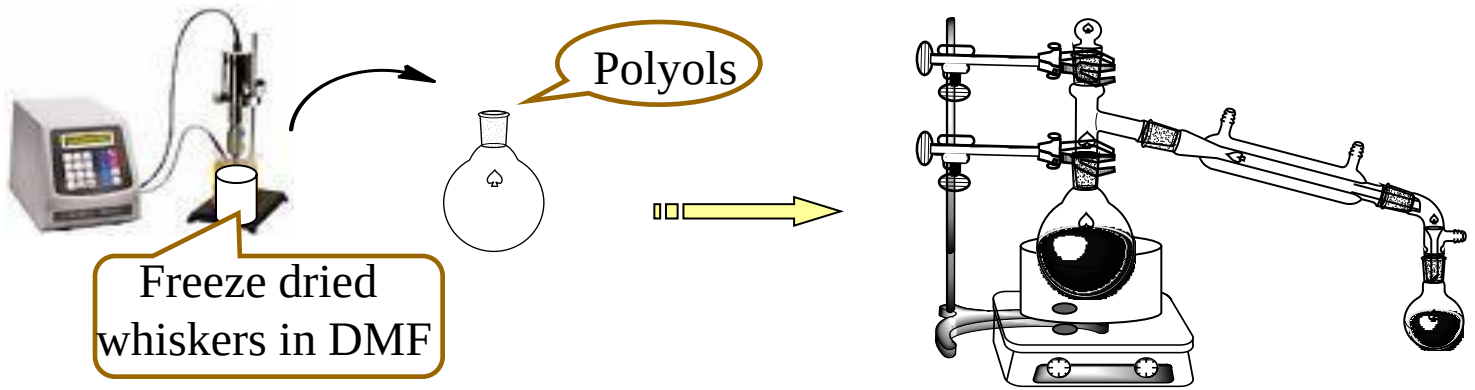
Preparation of pure PU foam (control)



Polyols, surfactant and catalysts → Polymeric MDI → Polymerization → Self-rising → Solidification

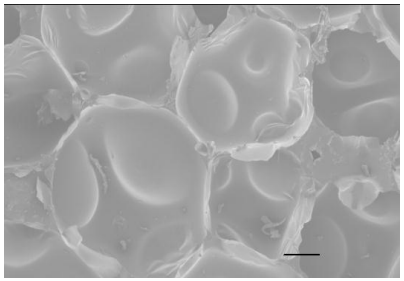
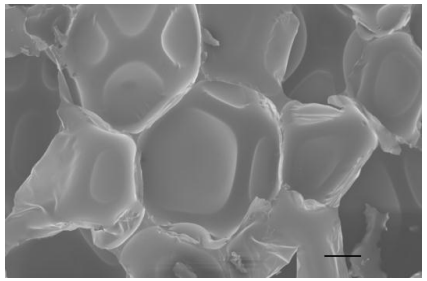
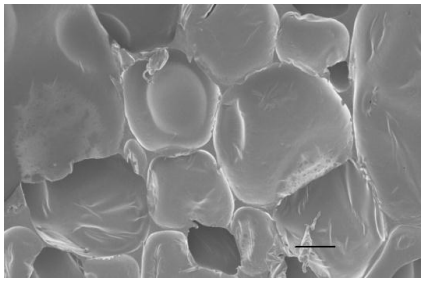
	S polyol	G polyol	MDI	DMCHA	octotate	pentane	surfactant
wt%	27.9	16.7	40.6	1.30	0.900	11.2	1.40

Preparation of PU nanocomposite foam



Foam structure characterization

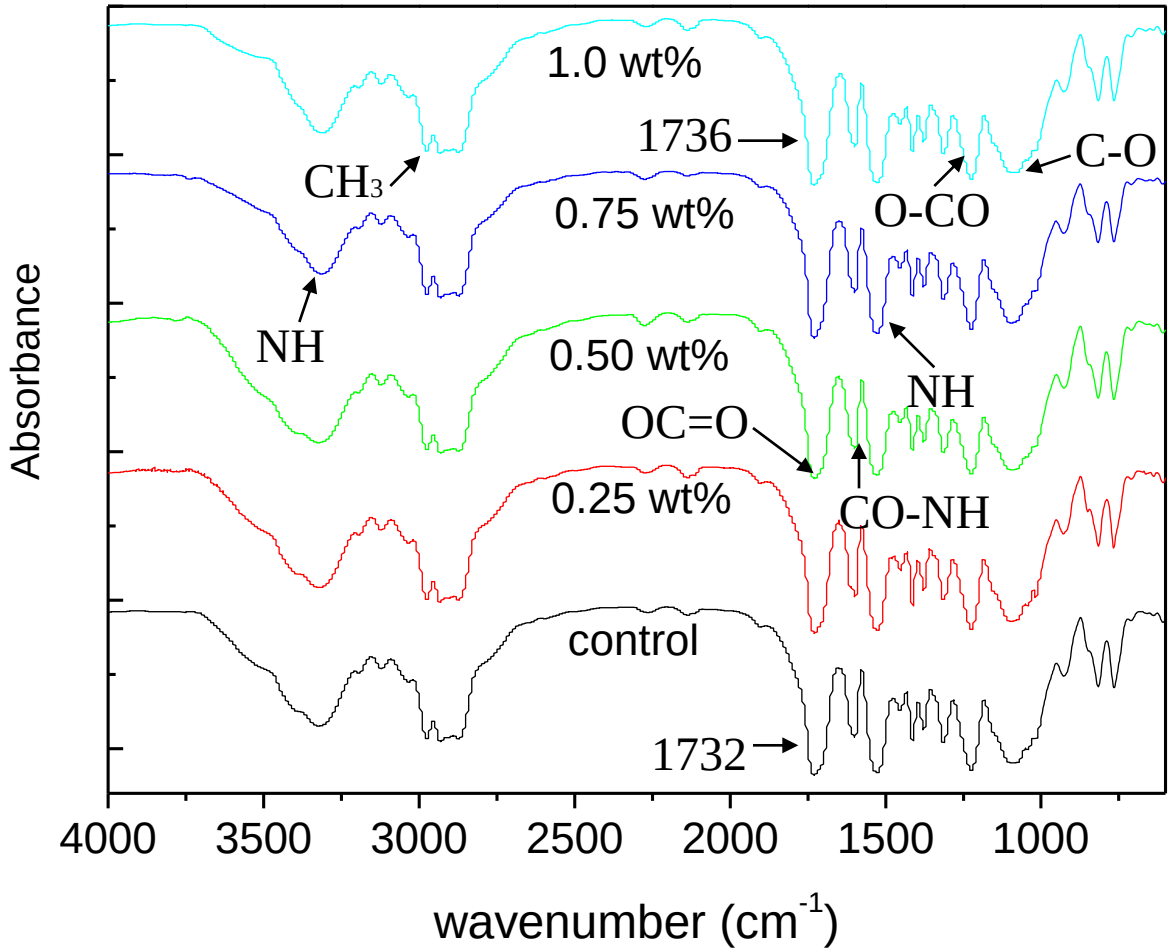
- Rigid PU Foams reinforced with 0, 0.25, 0.50, 0.75 and 1.0 wt% whiskers were prepared.
- Closed cells had a homogeneous dispersion, and cell sizes were all around 200 μm.

Scale bar: 100 nm.

Whisker wt%	0	0.25	0.50	0.75	1.0
Density (kg/m^3)	537.6 ±5.1	414.4 ± 5.1	461.6 ± 5.6	535.9 ± 3.3	820.1 ± 5.7

Fourier transform infrared spectroscopy



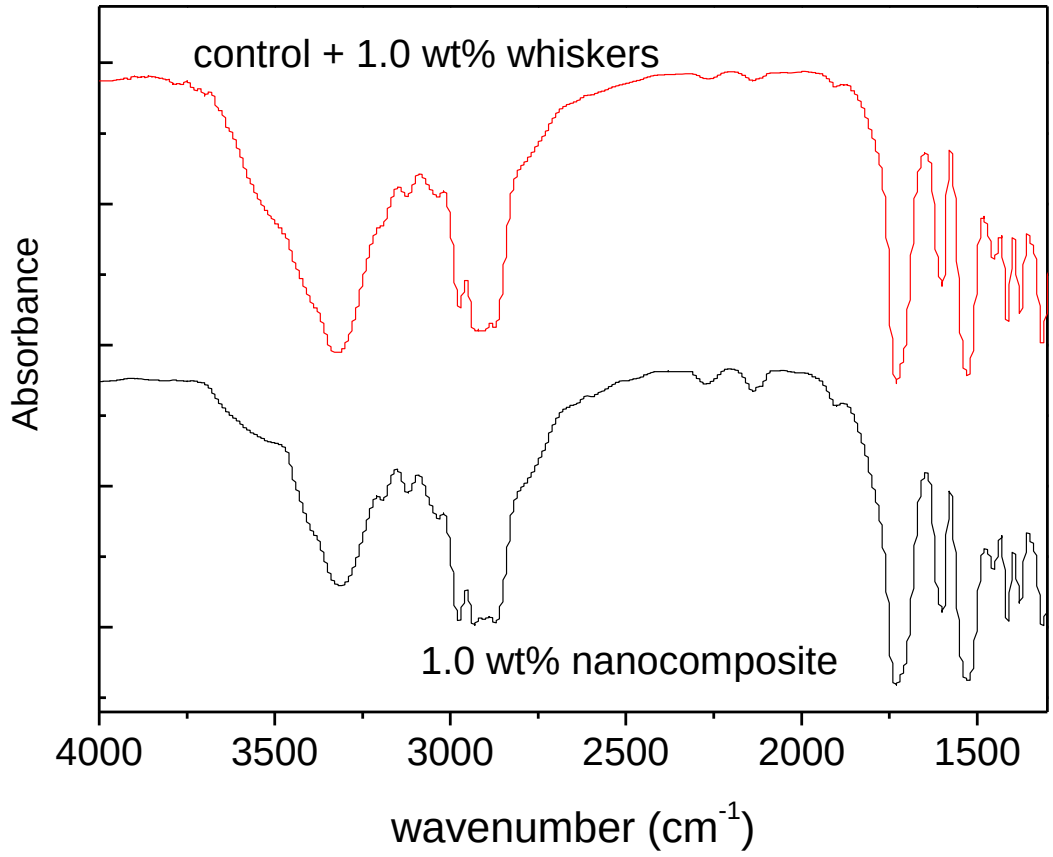
Urethane linkage

Polyether polyols
Cellulose whiskers

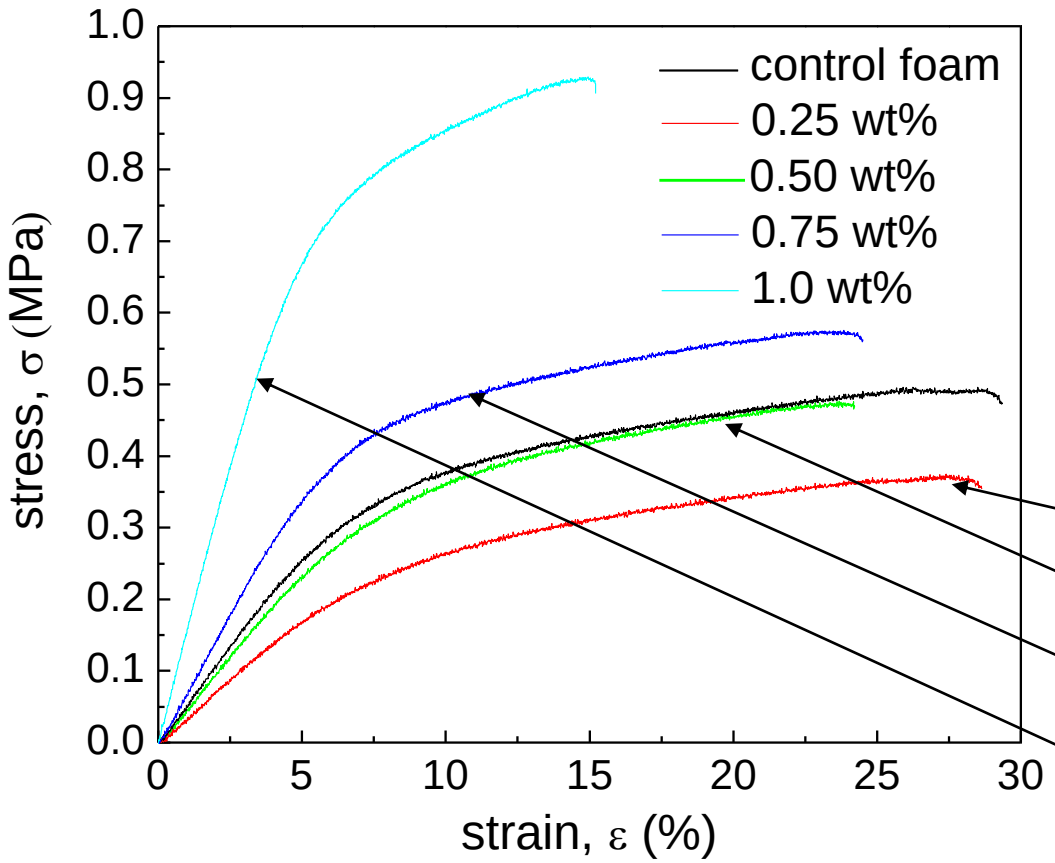
Interrupt H-bonding

Whiskers and PU interactions

Crosslinking happens between cellulose whiskers and isocyanates during polyurethane synthesis.



Tensile stress-strain curves

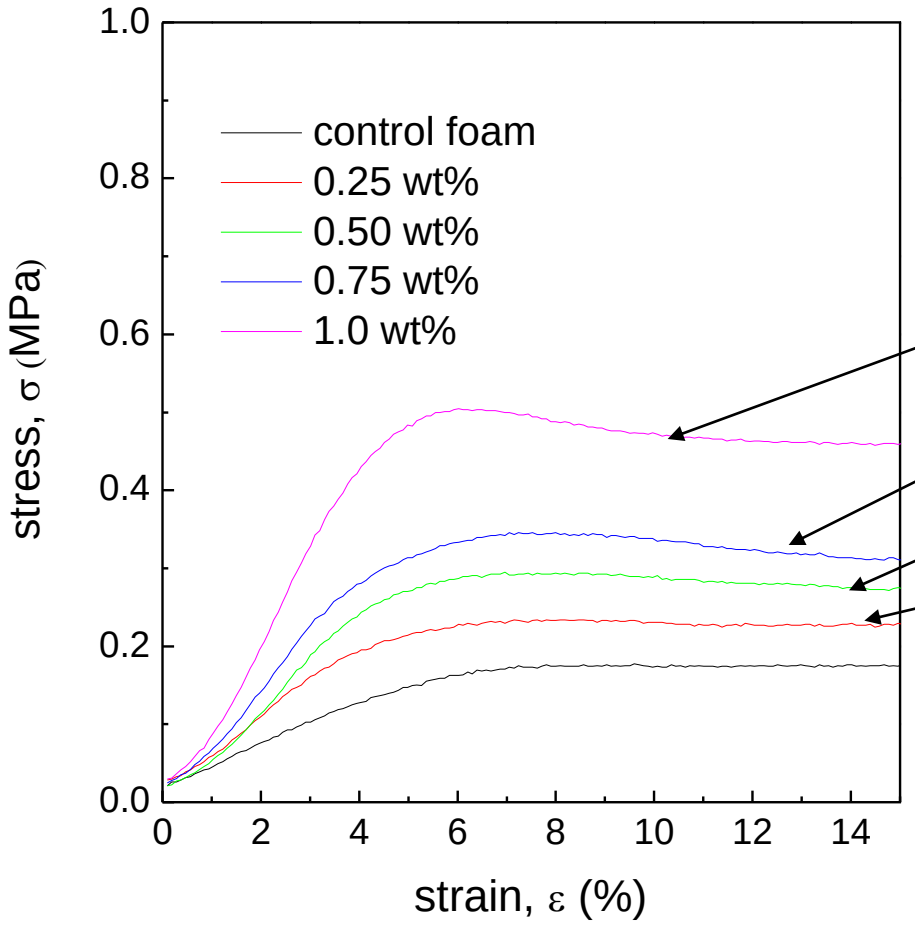


Tensile modulus
4.37 ± 0.14 MPa
Yield strength
0.316 ± 0.031 MPa
Tensile strength
0.485 ± 0.043 MPa

Changes (%):

-30.4	-34.2	-27.0
-20.6	-22.8	-21.4
36.8	15.2	13.8
227	112	99.2

Compressive stress-strain curves

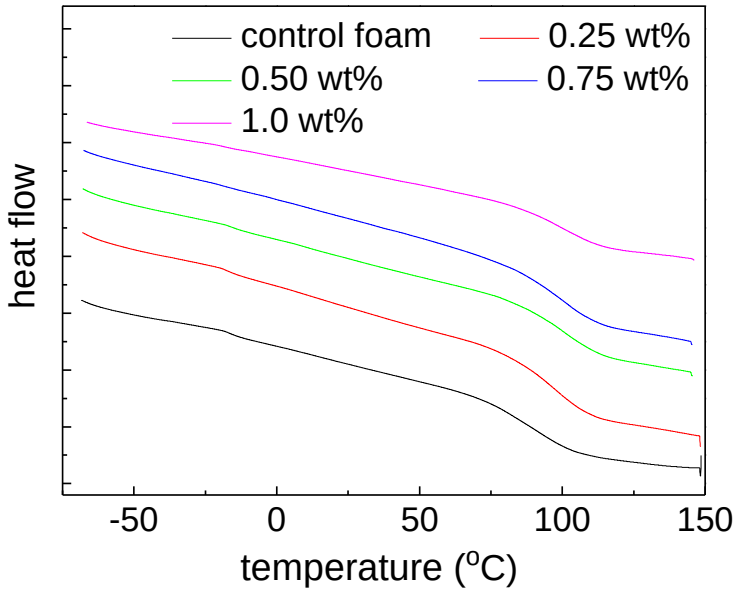


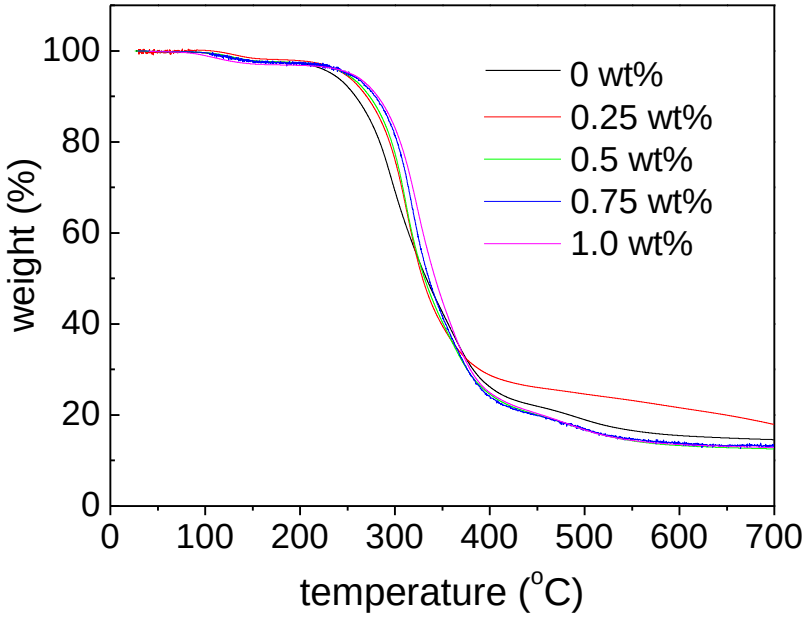
Gain (%):

210	270
180	143
118	131
66.6	29.0

Modulus 3.29 ± 0.85 MPa
Strength 0.145 ± 0.045 MPa

Thermal stability





Whiskers (wt%)	0	0.25	0.50	0.75	1.0
T_g (°C)	88	94	100	97	97
T_d (°C)	333	329	331	336	343

Conclusions

- Novel nanocomposites of rigid PU foam reinforced with cellulose whiskers up to 1 wt% have been prepared.
- The well-dispersed closed cells of different foams were all around 200 μm in diameter.
- Additional H bonding were developed in the nanocomposite, and crosslinking occurred between the whiskers OH groups and NCO groups.
- A substantial improvement of mechanical properties was obtained.
- Thermal stability of the nanocomposites was also enhanced.

Acknowledgements