Mineral Plastic Foams

Philipp Menold a,b, Helmut Cölfen a,*, Cosima Stubenrauch b,‡

a Physical Chemistry, University of Konstanz, Universitätsstrasse 10,
78457 Konstanz, Germany

b Institute of Physical Chemistry, University of Stuttgart, Pfaffentaldring 55,
70569 Stuttgart, Germany

*helmut.coelfen@uni-konstanz.de, 0049 7531 884063
‡cosima.stubenrauch@ipc.uni-stuttgart.de, 0049 711 685 64470
Scheme S1: Molecular structure of alkyl polyglucosides ($C_n G_m$). In our case $m = 1.5$, $n = 8-16$.

Figure S1: (left) Optical microscope image of the foamed liquid precursor, which was foamed via microfluidics and consisted of 0.1 M PAA, 0.1 M CaCl2, and 0.5 wt% Plantacare® 2000 UP. The separation of the bubbles (round shape) can be clearly seen. (right) Optical microscope image of the dried solid foam, so-called mineral plastic foam. For solidification a 0.1 M sodium carbonate solution was added to the liquid foam and subsequently dried in air. A homogeneous solid foam cannot be formed due to the low amount of PAA.
**Powder X-Ray Diffraction:** Powder X-Ray Diffraction (PXRD) measurements were carried out on a Bruker D8 Discover device equipped with a Vantec detector.

![X-ray diffractogram](image)

**Figure S2:** X-ray diffractogram of the white precipitate formed instead of mineral plastic. The precipitate was obtained by using a 1:10 mass ratio between sample and 4.0 M lithium hydroxide solution for the deprotonation of the PAA. The XRD pattern with peaks at 2Θ of 23.1°, 29.3°, 35.9°, 39.4°, 43.2°, 47.4°, and 48.4°, indicates that the sample is calcite.¹
**Mechanical Properties:** Mechanical compression tests were carried out with the zwickiLine 5 kN universal testing machine from Zwick / Roell, which was equipped with a 5 kN force transducer and was regulated by the testXpert III software. The stress-strain curves were obtained with normal forces and a test speed of 1 mm min⁻¹. A pre-force of 5.0 N was chosen to obtain a flat sample surface that was uneven from cutting with a scalpel. The slope of the linear part at the beginning of the stress-strain curve (cf. dashed regression line in Fig. S3) was used to determine the Young’s modulus $E$. It holds

$$ E = \frac{\sigma}{\varepsilon} = \frac{F \cdot l_0}{A \cdot \Delta l} $$

with $\sigma$ being the stress (force $F$ acting on a cross-sectional area $A$) and $\varepsilon$ being the strain (difference $\Delta l$ between the sample height before compression $l_0$ and after compression $l$). We obtained $E = 48.26 \pm 0.19$ MPa for a cube-shaped mineral plastic foam sample with a density of $327 \pm 31$ kg m⁻³.

**Figure S3:** Stress ($\sigma$) - strain ($\varepsilon$) curve with a pre-set force of 5.0 N for a cube-shaped mineral plastic foam sample with a density of $(327 \pm 31)$ kg m⁻³. The Young’s modulus of $(48.3 \pm 0.2)$ MPa was determined from the slope of the linear part (dashed curve) at the beginning of the stress-strain curve.
Solid foams have been studied extensively and there is general agreement that the relative Young’s modulus \( \left( \frac{E_{\text{foam}}}{E_{\text{polymer}}} \right) \) is proportional to the squared relative density \( \left( \frac{\rho_{\text{foam}}}{\rho_{\text{polymer}}} \right)^2 \). It holds for open-pore systems

\[
\frac{E_{\text{foam}}}{E_{\text{polymer}}} = C_c \cdot \left( \frac{\rho_{\text{foam}}}{\rho_{\text{polymer}}} \right)^2
\]

(2)

with \( C_c \sim 1 \) according to Gibson and Ashby.\(^{2-4}\) Using \( E_{\text{polymer}} = (380 \pm 2) \) MPa (experimental stress-strain curve not shown) and \( \rho_{\text{polymer}} = (1117 \pm 4) \) kg m\(^{-3}\), one obtains a relative elastic modulus \( \left( \frac{E_{\text{foam}}}{E_{\text{polymer}}} \right) \) of 0.127 and a relative squared density \( \left( \frac{\rho_{\text{foam}}}{\rho_{\text{polymer}}} \right)^2 \) of 0.086. The resulting proportionality factor \( C_c \sim 1.5 \) is in the usual range.

References
1. C. G. Kontoyannis and N. V. Vagenas, Analyst, 2000, 125, 251.