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Acoustic parametrisation of gellan gum

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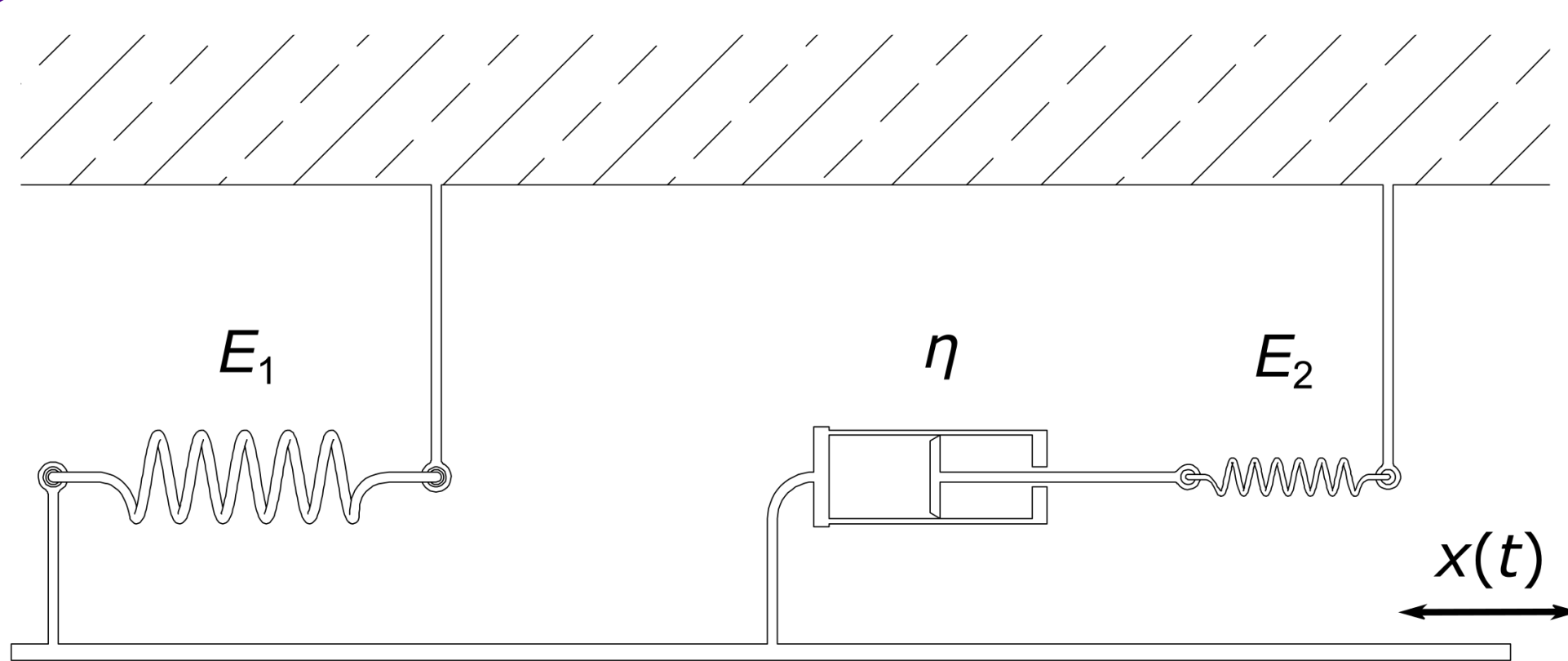
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Gellan gum is a hydrogel with several applications in ultrasonic imaging, novel drug delivery, and tissue regeneration. As hydrogels are dynamic entities, they are viscoelastic and therefore their acoustic properties change over time, which is of interest to monitor. To determine the speed of sound from brightness-mode images, however, rather large quantities of hydrogel are needed. In this study, we investigated torsion rheometry as a means to determine acoustic properties. Perceived speeds of sound were derived and computed from torsion rheometry measurements of gelling gellan gum mixed with spermidine trihydrochloride crosslinker. For comparison, brightness-mode ultrasonic images were recorded of the same material inside a phantom well. The rheometry data converged to a speed of sound within a standard deviation of the speed of sound measured from the brightness-mode images. We have shown that dynamic acoustic properties of gelling gellan gum can be simulated and experimentally determined using torsion rheometry.

Theory



Maxwell representation of a Zener model of an isotropic hydrogel, adapted for shear strain and subjected to a periodic displacement function $x(t)$.

Storage modulus

$$G'(t) = E_1 \left(1 - e^{-\frac{E_2}{\eta} t}\right)$$

Loss modulus

$$G''(t) = \eta \omega \left(1 - e^{-\frac{E_2}{\eta} t}\right)$$

where

- E_1 – elasticity of the storage component
- E_2 – elasticity of the loss component
- η – dynamic viscosity of the loss component
- ω – angular displacement frequency

Dynamic modulus

$$|G^*(t)| = \sqrt{G'(t)^2 + G''(t)^2}$$

Perceived speed of sound

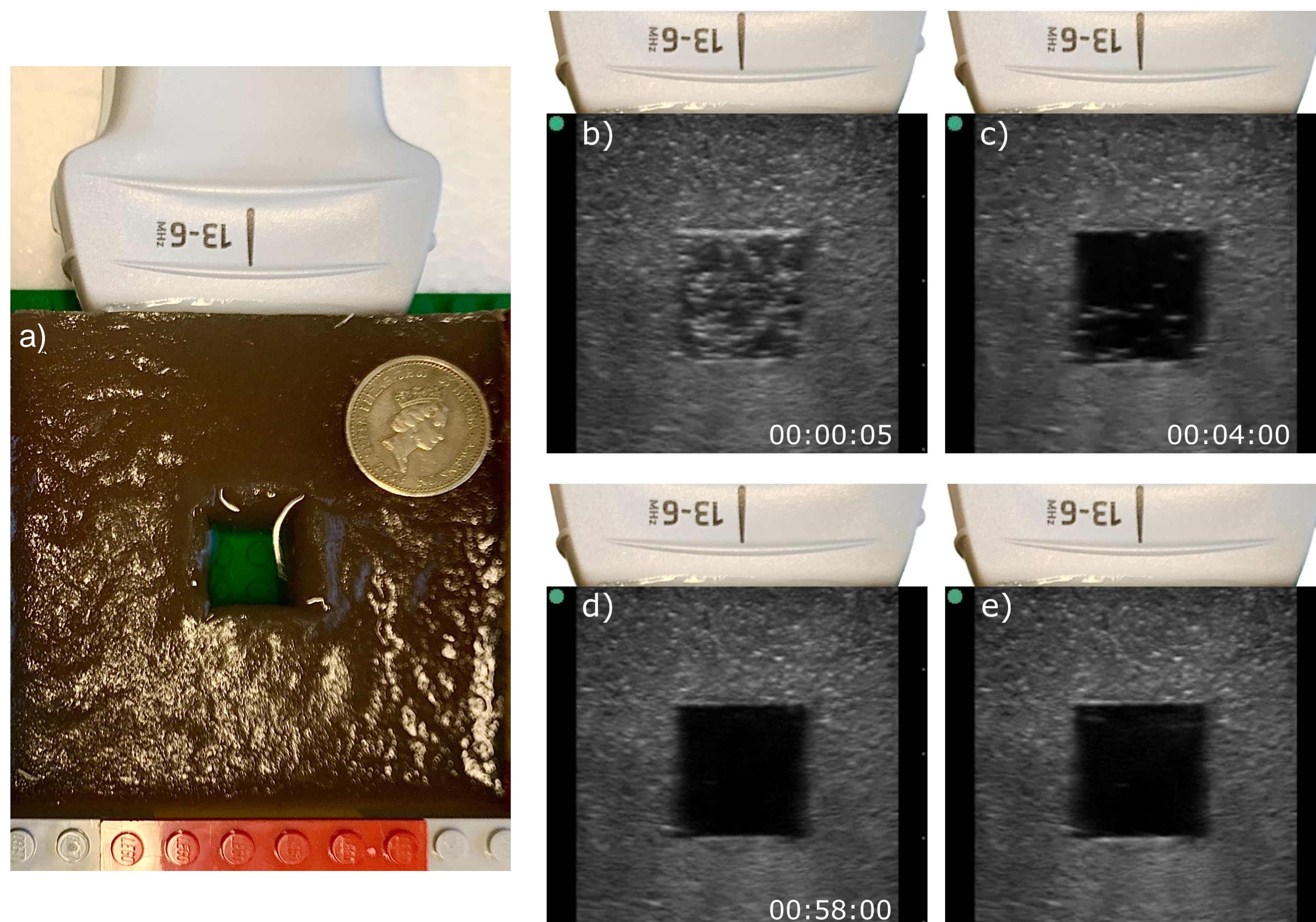
$$c(t) = \sqrt{\frac{3 |G^*(t)|}{\rho}}$$

Speed of sound

$$c(t) = \sqrt{\frac{2G(t)(1+\nu)}{\rho}} \approx \sqrt{\frac{3G(t)}{\rho}}$$

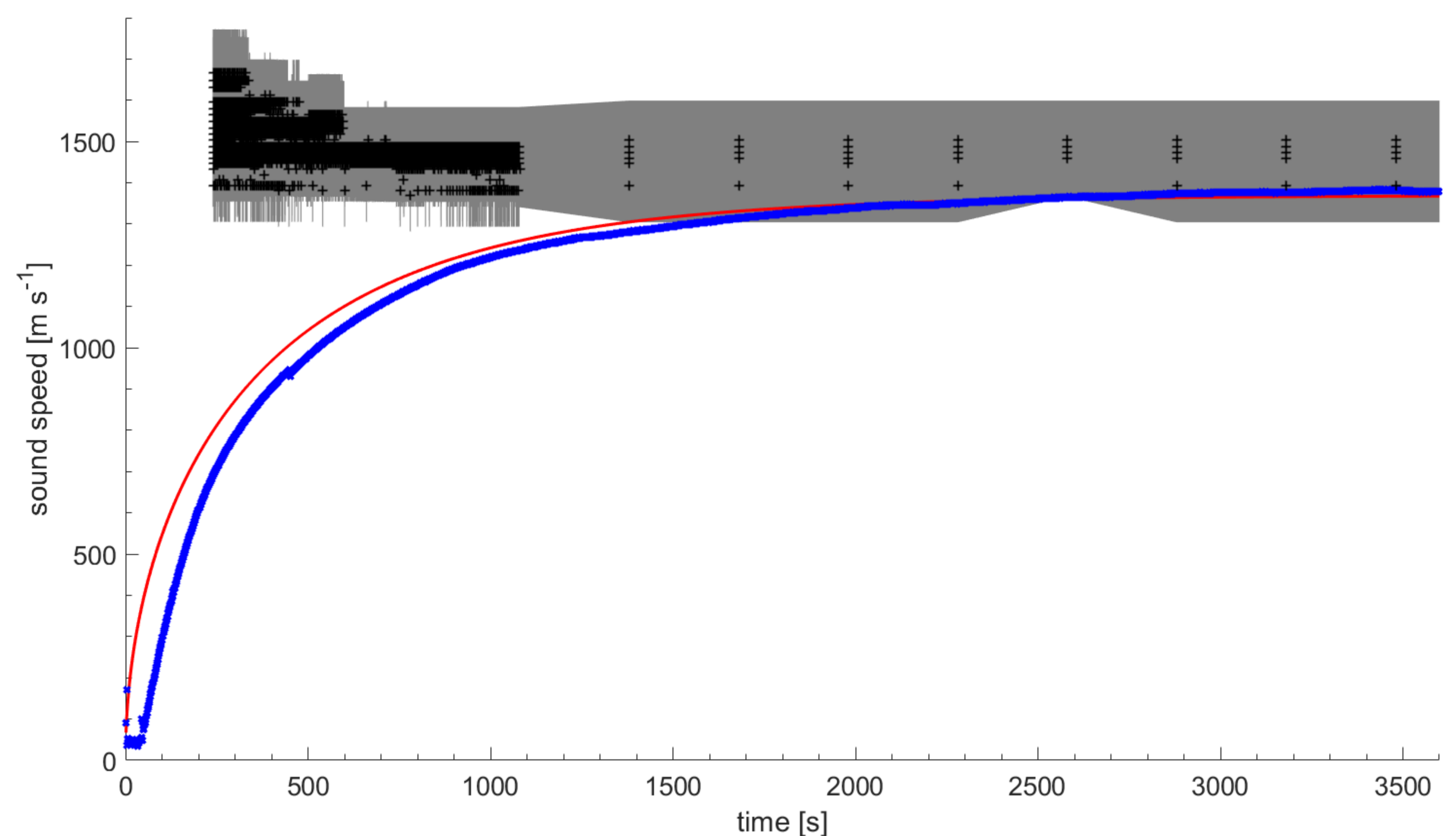
$$\lim_{t \rightarrow \infty} c(t) = \lim_{t \rightarrow \infty} c(t)$$

Results



Top view of the position of the ultrasound probe with respect to the phantom and the cuboid well filled with optically transparent hydrogel (a). A £1 coin has been added for scale.

Brightness-mode images of the cross-section of a cuboid well filled with gelling gellan gum at selected times (b-d) and a control with prepared water (e).



Perceived speed of sound of gellan gum as a function of gelation time, measured from brightness-mode ultrasonic images (black with grey error bars), perceived from torsion rheometry (blue), and simulated from rheometry input (red).

Materials and methods

1. Gellan gum

- 0.5% w/v G1910 Gelzan™ CM Gelrite in HEPES/sucrose.
- 1:5 ratio of spermidine trihydrochloride crosslinker:gellan gum.

3. Ultrasonic imaging

- HFL38x 13–6-MHz linear probe of a SonoSite® M-Turbo® sonography device horizontally touching the front face of the phantom.

2. Phantom

- 80.0x80.0x39.9mm³ tissue-mimicking material with a 15.8x15.8x39.9mm³ cuboid well 32.2mm from the front face.

4. Rheometry

- Rheological time sweep experiments performed with a DHR-2 hybrid rheometer in torsion mode.

Conclusions

Feasibility of using rheometry input for modelling and estimating the speed of sound during the gelation of gellan gum demonstrated.

Perceived speed of sound of gellan gum after an hour was 7.5% less than the mean speed of sound measured from brightness-mode images, but within a standard deviation.

Author statement

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