Electronic Supplementary Material (ESI) for ChemComm.

Supporting Information

Impact-Induced Gelation in Aqueous Methylcellulose Solutions

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This PDF file includes:

Other Supplementary Materials for this manuscript include the following:

Movies S1 to S4

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Section 1: Preparation of Materials

1.1. Preparation of AMCS

The 5.6% wt. aqueous methylcellulose solution was prepared by adding 16.8 g methylcellulose (SG A7C food grade, DOW chemicals) to 200 mL ultrapure water (resistance=18 MΩ, Millipore Milli-Q instrument) at 70 °C. The mixture was manually stirred and then an additional 100 mL cold (4 °C) water were added while stirring. The solution was then placed in an ice bath for one hour and then kept for at least overnight and up to 3 days under refrigeration (4-8 °C) before use.

1.2. Preparation of BG Solution

The 5% wt. ballistic gelatin solution was prepared by adding 5 g. of pork gelatin powder (300 Bloom, MM Ingredients) into 95 mL of water at 70 °C. The solution was manually stirred at 70 °C for at least 5 minutes until all the powder was well-dissolved. The solution was then cooled and kept in refrigeration for at least overnight (and up to one day) before use.

Section 2: Experimental Data on the Instrumented Hopkinson (Kolsky) Bar System Setup and Parameters

All mechanical experiments were repeated over a dozen times to assure repeatability of the reported results.

2.1 Shock Attenuation Experimental Setup

The experimental setup consists of a liquid-containing chamber with internal dimensions of h=93, w=96, d=20 mm, made of 10 mm thickness aluminium plates. A set of HT201 FlexiForce® sensors, was placed on the inner side of the impacted and the rear chamber's walls. Before each experiment, the chamber and the solution were thermally equilibrated at 23±2 °C. The impact loading was generated using a 12.7 mm diameter Kolsky apparatus made of 7075-T6 aluminium alloy, equipped with a pressurized gas gun and a 15 cm projectile made of the same material. As the striker hits the Kolsky bar, an elastic stress wave starts to propagate towards the bar's far edge, which is in contact with the aluminium chamber. As the stress wave reach the bar's far end/chamber interface, part of the wave continues to propagate in the original direction into the impacted wall's chamber and into the AMC solution. This wave is recorded on the force sensors, so force comparison can be made before and after the solution. The other part of the stress wave is reflected back to the Kolsky bar. By recording the original and the reflected signal, the impact force profiles can be calculated. These were in the range of 2500-14,000 N.

2.2. Impact Gelation High Speed Photography Experimental Setup

The same instrumented Hopkinson (Kolsky) system described in C1 above was used. A custom non-reflective aluminium chamber equipped with a transparent glass window and a bar insertion orifice, with an open top, h=15, w=15, l=40 mm was mounted on the free edge of the Hopkinson bar and filled with the tested liquid. The chamber and the solution were thermally equilibrated at 23±2 °C prior to impact. The impacts generated by the projectile, typically translate to forces in the range of 2,500-10,000 N. The velocities of the bar were in the range of 13-20 $m \cdot s^{-1}$, with a characteristic rise-time of 15-20 μsec and a pulse duration of 120 μsec. The impact was monitored using a high-speed camera (Kirana, 8M fps), operated at a frame rate of 500,000 to 1,000,000 fps, synchronized with a pulsed white light flash. The trigger of the camera was activated by a strain gauge, whose location on the bar along with the wave velocity provides a 120 μsec gap from the time of trigger to the time the impact reaches the liquid in the chamber.

Section 3: Calculation of Impact Energies Delivered to the Solution

The energy supplied to the MC solution was calculated using the elastic strain energy balance in the impacted bar. Once the striker hits the Hopkinson bar, a compressive stress wave (ε_I) starts propagating along the incident bar until reaching its end. Upon reaching the bar-solution interface, part of the incident stress wave propagates in the original direction (into the solution) while another part is reflected back through the incident bar (ε_R). A typical Hopkinson signal, recorded using strain gauges is shown in Figure S1.

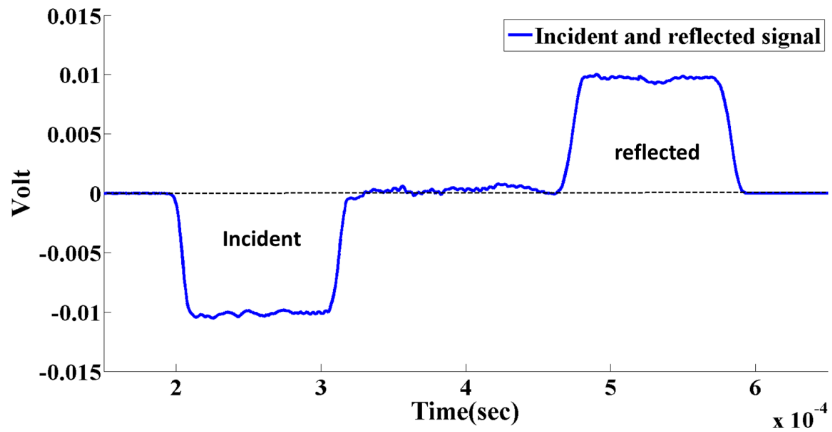

Figure S1. Typical Hopkinson signal, as recorded by the strain gauges. Negative voltage corresponds to compressive strain and positive voltage corresponds to tensile stress.

The elastic strain energy of ε_I and ε_R, denoted as E_I and $E_R$respectively, is calculated as

Energy=$\int \sigma \cdot d\varepsilon = E \cdot \varepsilon \cdot d\varepsilon$

Where E is the Hopkinson bar's elastic modulus (E=71.7GPa) and σ and ε are the stress and the elastic strain in the bar respectively. For elastic strains, the stress is equal to E·ε. A representative comparison between incident and reflected signals for energy calculation is shown in Figure S2.

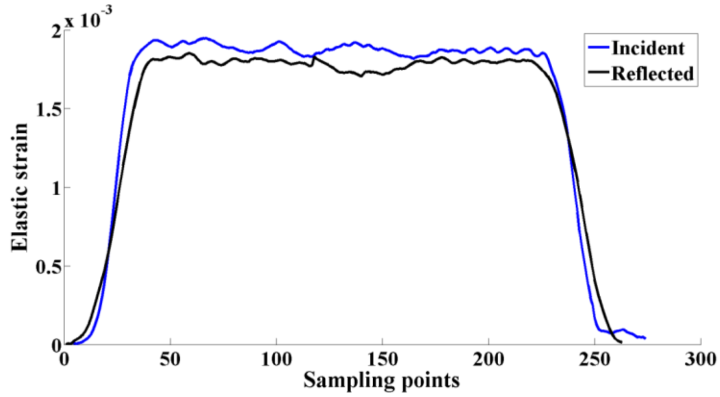

Figure S2. Typical incident and reflected signals in a comparative mode.

The energy difference between E_I and E_R is the energy supplied to the solution.

Section 4: Graphical Analysis of Gel Formation

The opaque area in the frames of the movie was selected and marked, using GIMP Image Editor version 2.8. The program then analyzes the selected area's brightness and provides statistical data on its distribution. The mean value of the brightness was taken for each area and used to construct the gel formation graph. An example of the selected opaque area and the output of the graphical analysis is shown in Figure S3.

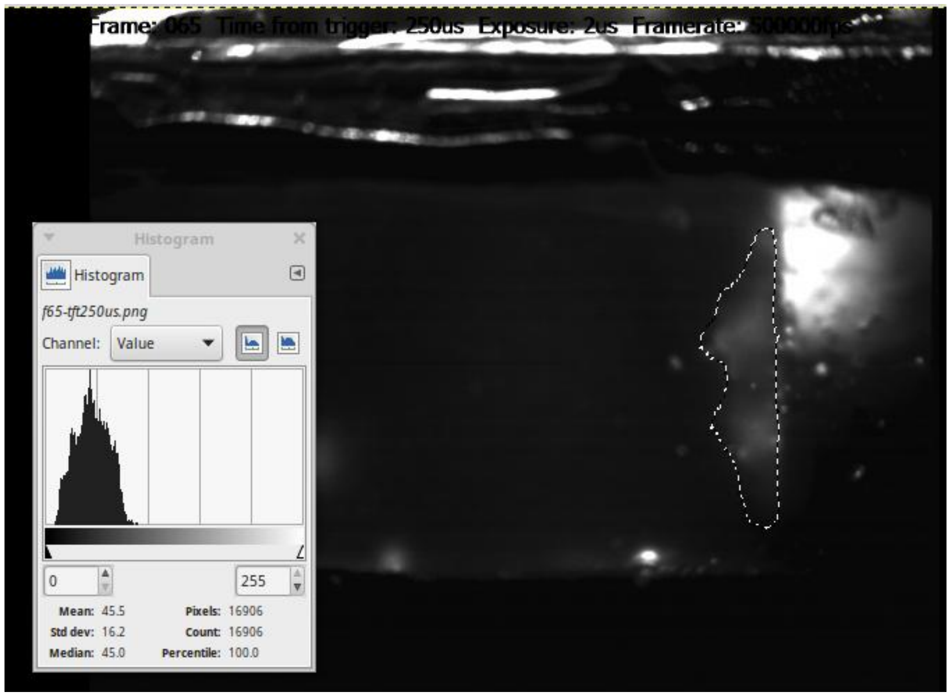

Figure S3. Example of opaque area selection and the corresponding statistical analysis output of its brightness.

Section 5: Observation of Heat-induced Gelation in the Experimental System

In order to verify that the experimental system (including the setup of the blackened cell, the flash-lighting and high speed camera, and the method of image analysis) is suitable to observe gelation-induced opacity, it was used to observe gelation of the AMCS due to heating.

The 5.6% wt. AMCS was loaded into the impact cell, which was covered with an additional glass plate on its top (to avoid water vapor loss) and the orifice for the Hopkinson bar insertion was sealed with plasticine into which the leads of a thermocouple were inserted, so that they were situated within the solution. This cell (and its contents) was then heated in a water bath, stabilized at each temperature value for 5 minutes and then removed from the water bath and filmed with the high speed camera in the experimental setup. Image analysis was performed identically to the method detailed in Section 4, but in this case the selected area was from the middle of the cell's content. The mean value of the brightness was taken for each area and used to construct the gel formation graph. An example of the selected opaque area and the output of the graphical analysis is shown in Figure S4, and the resulting graph is shown in Figure S5.

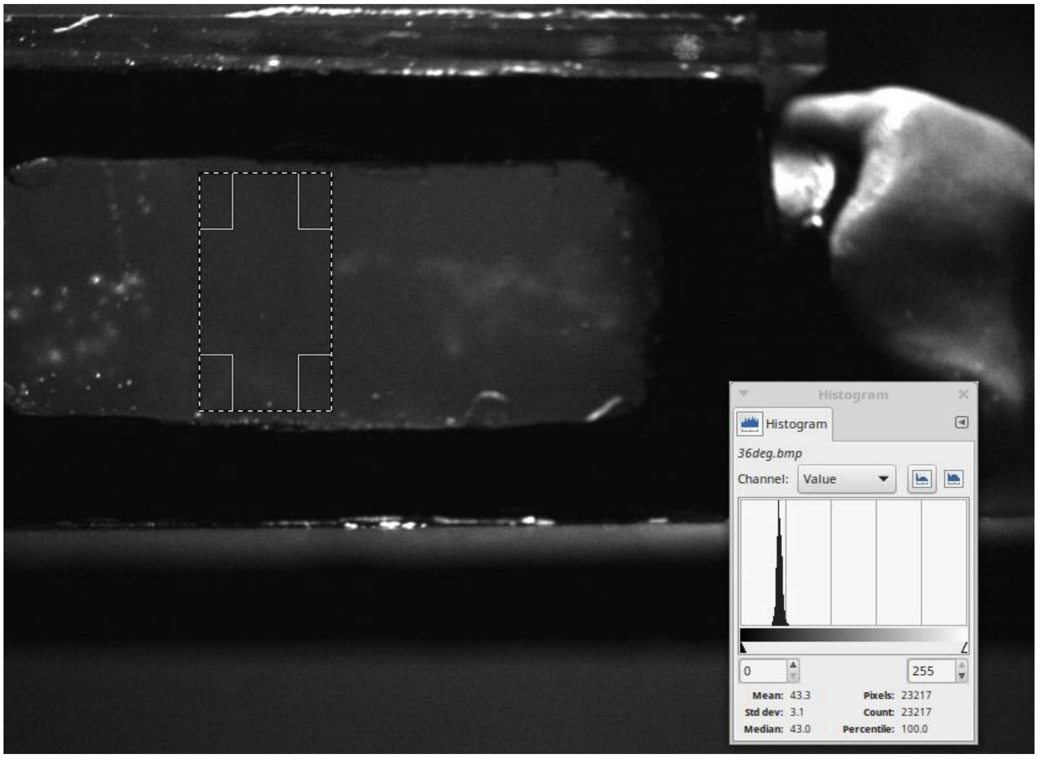

Figure S4. Example of opaque area selection and the corresponding statistical analysis output of its brightness.

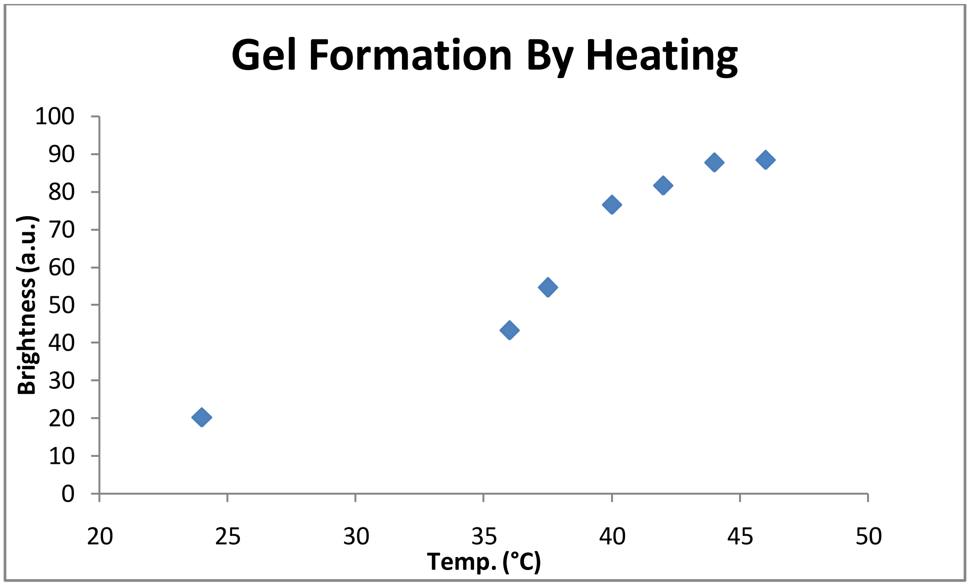

Figure S5. Graph of gel formation due to heating – opacity of the AMCS (in brightness arbitrary units as derived from image analysis) as a function of the AMCS temperature (values in ±0.2 °C), as obtained by use of the high-speed camera experimental system.

It is noted that according to literature,[1] the value of 86% opacity (from clear solution to the opaque gel) best corresponds to the temperature of gelation. Applying this correlation to the graph in Fig. S5 provides a good fit to the AMCS temperature of gelation (42 °C).

Reference:

S. A. Arvidson, J. R. Lott, J. W. McAllister, J. Zhang, F. S. Bates, T. P. Lodge, R. L. Sammler, Y. Li, M. Brackhagen, *Macromol.*, 2013, **46**, 300-309.

Supporting Movies: Captions

Movie S1.

High speed camera film for impact of room temperature AMCS.

Movie S2.

High speed camera film for impact of room temperature water.

Movie S3.

High speed camera film for impact of room temperature ballistic gelatin.

Movie S4.

High speed camera film for impact of room temperature AMCS, with the impacting bar set close to the rear of the chamber.