IMPRESS: Impact Modelling of Polymers: high-Rate Experiments for Solid-state Simulations

Grace. M. Owen

Supervisors: Davide De Focatiis, Gabriel Choong, Stewart McWilliam

1. Introduction

Filled and unfilled polymeric materials are frequently used in products exposed to high-rate loading, or **impact events** (e.g., car bumpers, aircraft fuselages and bone supports). Impact conditions refer to strain rates **greater than 1000 s^{-1}** [1]. However, polymeric material behaviour during impact is not entirely understood, which **hinders optimisation** of the material properties, resulting in final products that are **heavier** or **less effective**.

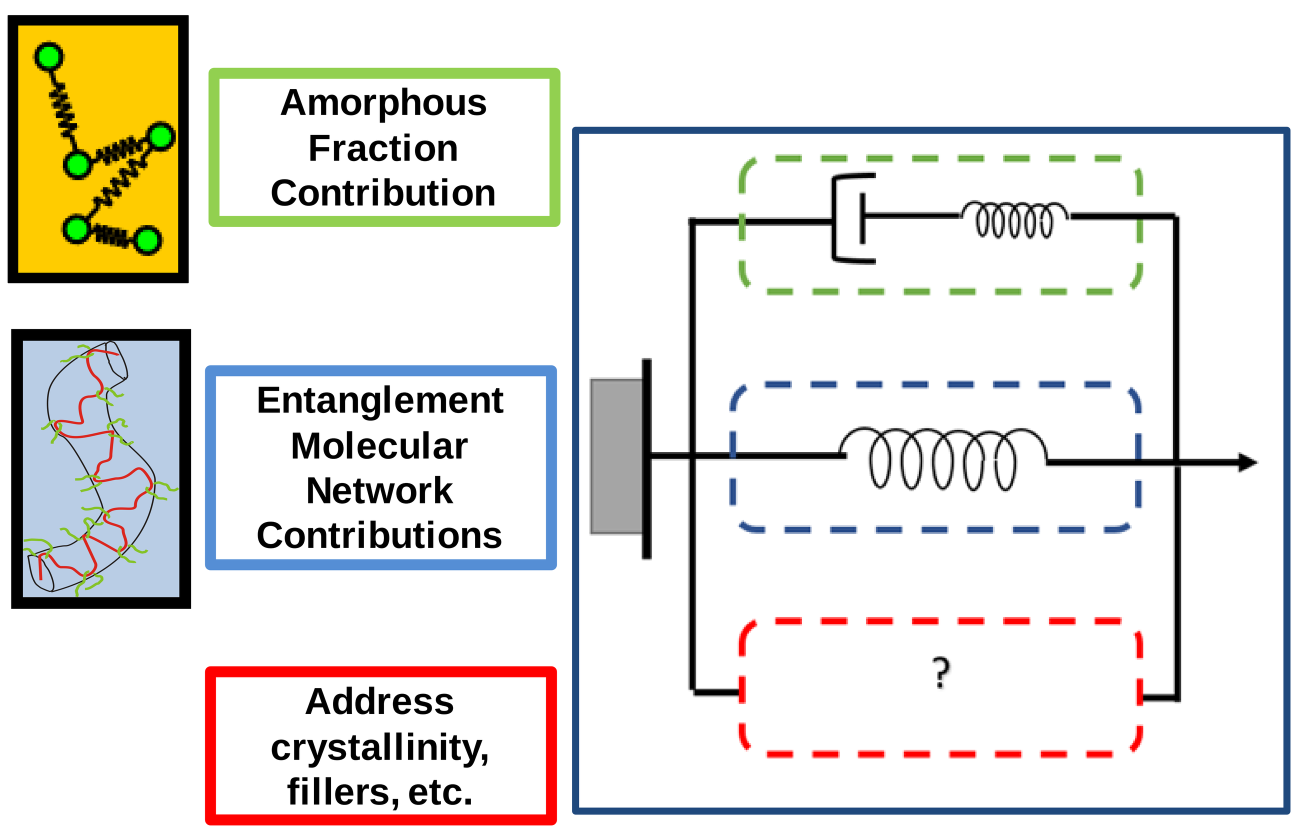
Aims: To develop a physically-based constitutive model that is able to *predict* the constitutive response of polymer systems across a *broad range of strain rates*.

Outcome: To produce high performance, recyclable, polymers optimised to work efficiently in impact loading conditions.

2. Challenges

- During impact conditions, some parts of the material experience **high rate impact conditions**, other parts are experiencing **slower strain rates** – necessary to simulate the **entire range of rates**.
- Polymers are **very sensitive** to certain factors such as **temperature** and **strain rate**; this is exacerbated at lower temperatures or higher strain rates.
- As the strain rate increases, there is a change to **adiabatic heating** from isothermal conditions.

3. Model Development



The **bond-stretching** contribution addresses the viscous and elastic parts through Eyring rate kinetics. The material for Parameterisation of unfilled amorphous systems is polycarbonate (PC). This contribution dominates the yield process.

The '**rubbery**' part – the **conformational** free energy is modelled as an entropic network of entanglements using an Edwards-Vilgis function. The strain-hardening seen in Fig. 1 is dominated by the rubbery response.

Future work will address **semi-crystalline** materials, mainly **polyamides,** and **filled** systems, specifically **short fibre reinforced PC** (homogenous approach).

4. Novel Aspects and Progress

To address these **complexities** of impact rate modelling, two key features have been added:

(1) **Adiabatic heating:** Implementation through modelling the rate of heating, as seen in Fig. 2. This includes a contribution from the changing structure reducing the amount of energy going towards heating. The blue line in Fig. 2 highlights the difference if the energy going into structural change was ignored.

(2) Ageing and mechanical rejuvenation have been implemented through applying a **structural evolution** implementation with a spectrum of *fictive temperatures,* T_f :

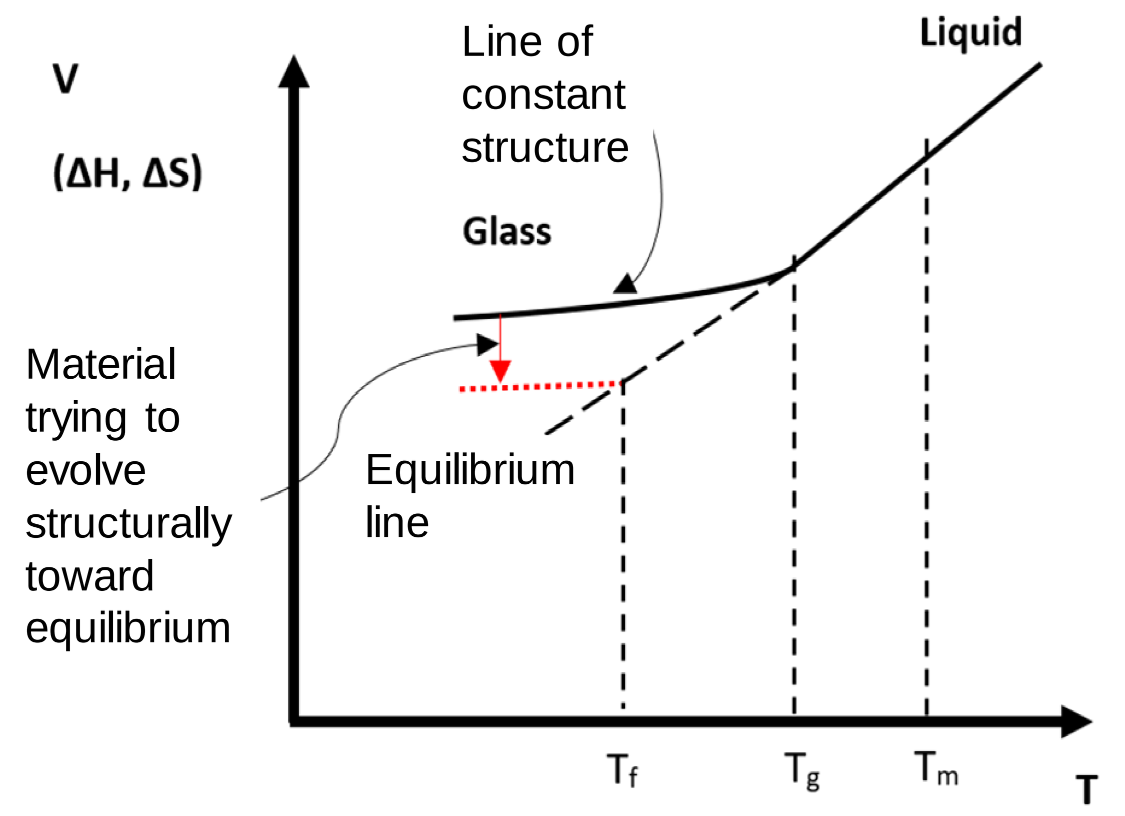
$$\dot{T}_f = \frac{T_f - T}{\tau} + \kappa\dot{\bar{\varepsilon}}^v$$

where κ is a material parameter, $\dot{\bar{\varepsilon}}^v$ is the rate of effective viscous strain.

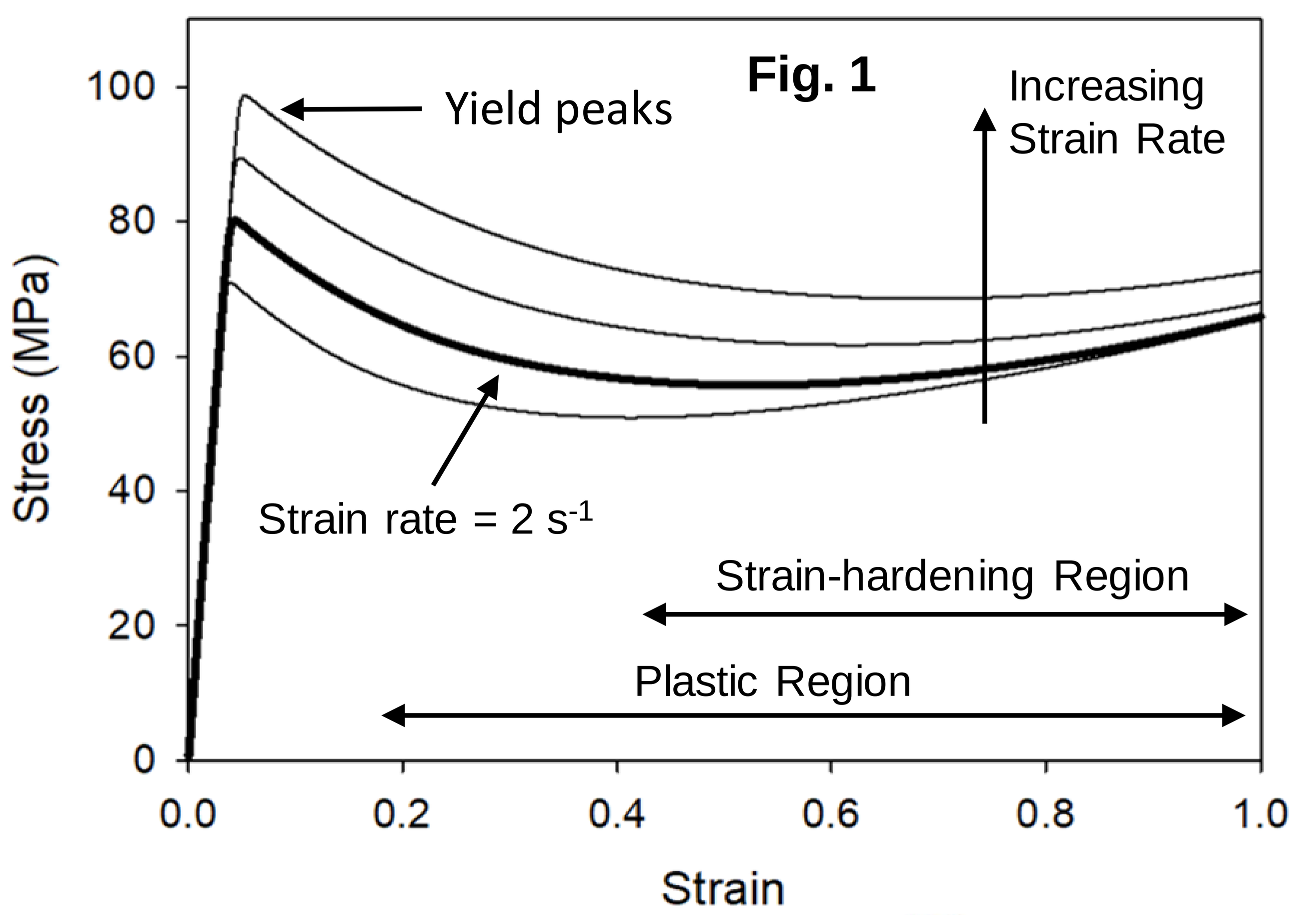
This novel implementation leads to the convergence of flow stresses as seen in Fig. 1, and is more accurate than previous models. This has opened a deeper exploration of the approach and the fictive temperature concept. Fig 3 shows how T_f varies with strain rates.

What is *fictive temperature*?

The temperature at which a material would be in equilibrium if suddenly brought to it from its current state.

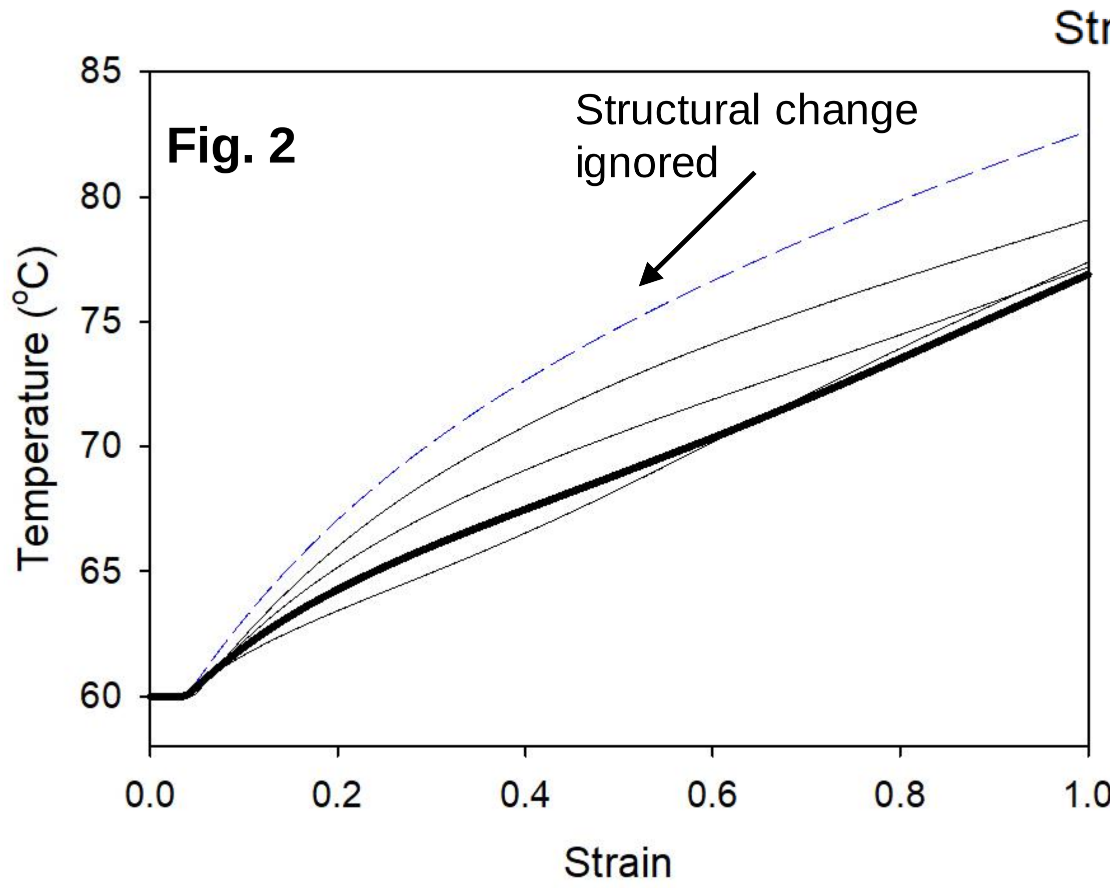


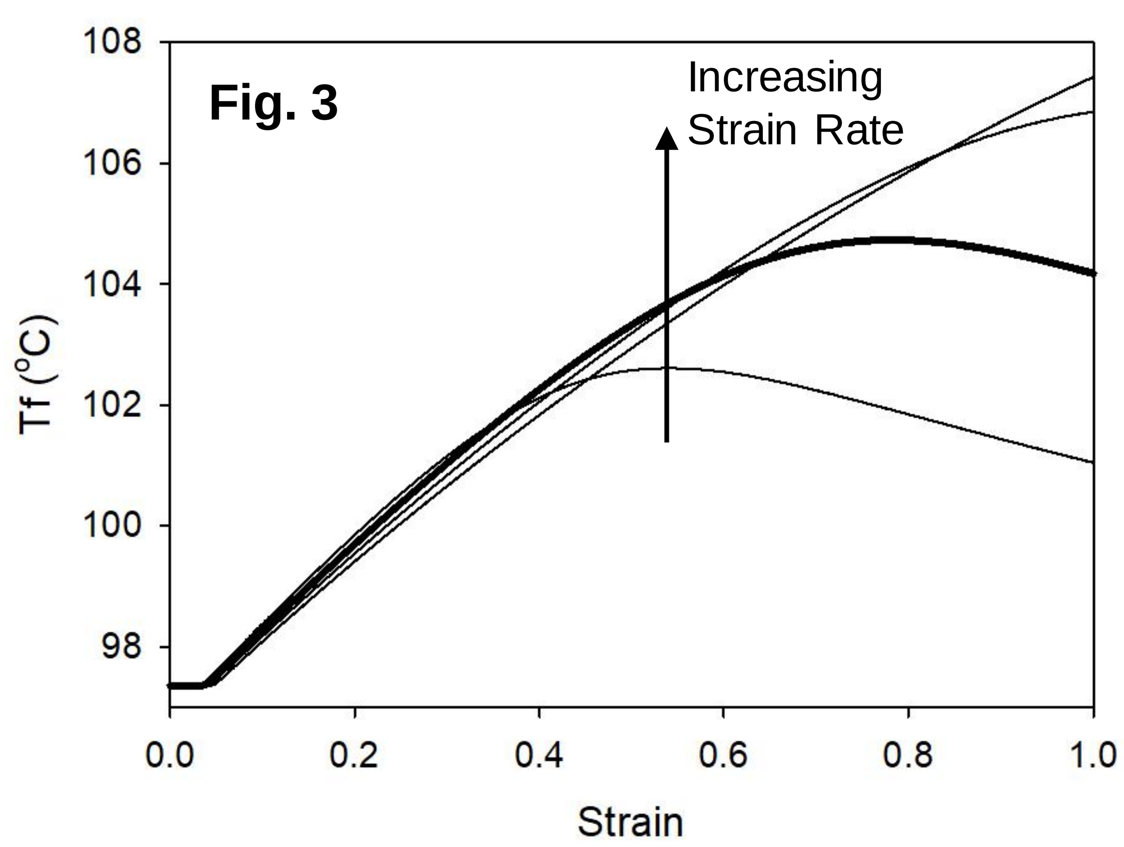
5. Results



Material: Polystyrene

Fixed temperature = 60 °C





Reference: [1] MI Okereke, CH Le, and CP Buckley (2012) *EPJ Web of Conferences*, 26, 04031.

Composites Research Group

eaygo@nottingham.ac.uk

DPI The Polymer Research Platform

UNIVERSITY OF OXFORD