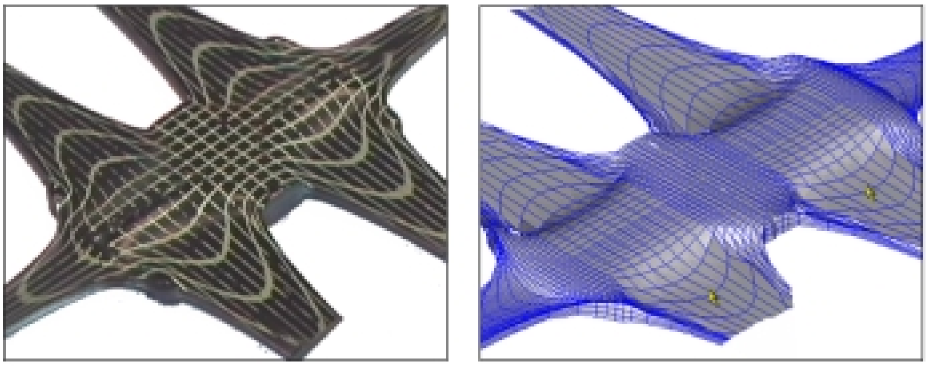
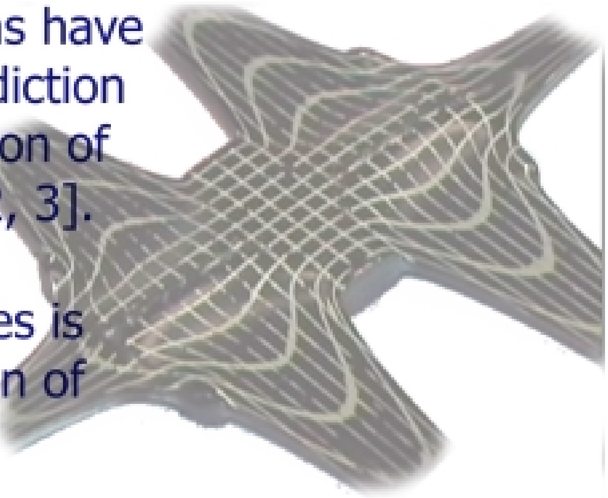
Solid Phase Drawing of Polymers: Experimental Validation of Constitutive Equations



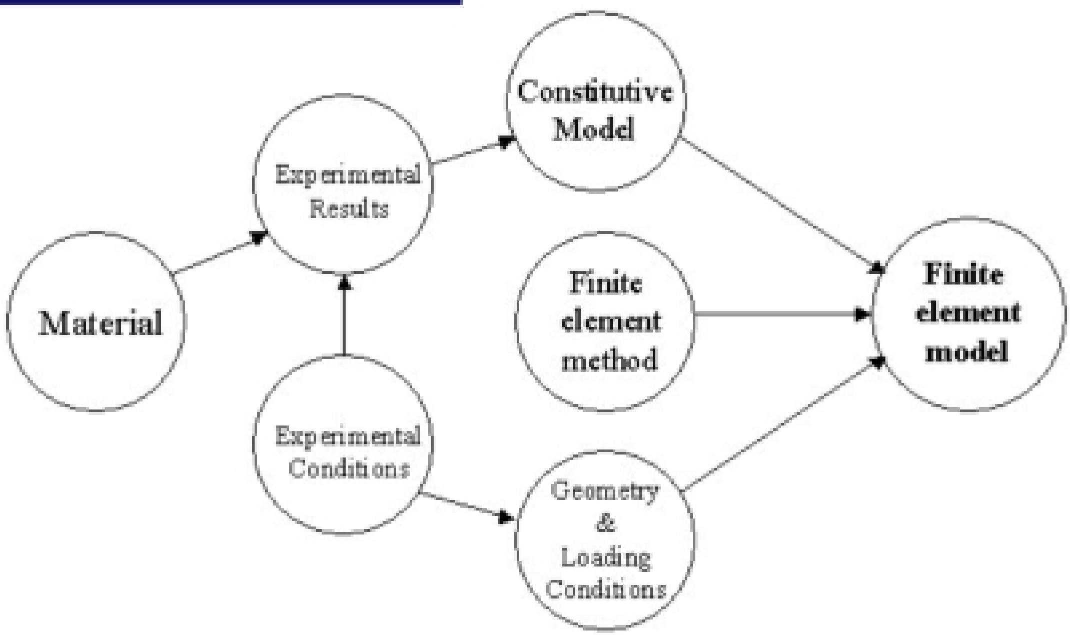
P Caton-Rose, J Sweeney, A S Wood, G Rosala & P D Coates
Department of Mechanical and Medical Engineering,
University of Bradford,
Bradford,
BD7 1DP

Introduction

In recent years constitutive equations have been developed that enable the prediction of shapes generated by the application of large deformations to polymers [1, 2, 3].



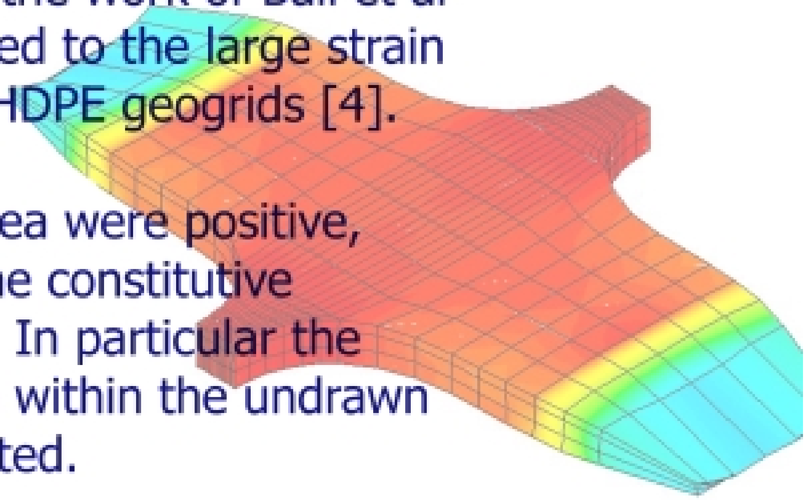
However, application of these theories is strongly dependant on the acquisition of relevant material data and therefore experimental techniques.



1. J. Sweeney and I. M. Ward,
   J. Mech. Phys. Solids, 44 1033-1049 (1996)
2. J. Sweeney, T. L. D. Collins, P. D. Coates and R. A. Duckett,
   Journal of Applied Polymer Science, 72 563-575 (1999)
3. I. M. Ward, P. D. Coates and M. M. Dumoulin (eds.) 2000,
   Solid Phase Processing of Polymer, Hanser Munich (2000)

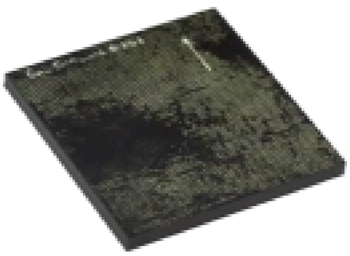
HDPE Analysis

An elastic theory based on the work of Ball et al has been successfully applied to the large strain isothermal deformation of HDPE geogrids [4].



Whilst results within this area were positive, significant deficiencies in the constitutive theory were demonstrated. In particular the presence of pre-orientation within the undrawn sample could not be predicted.

Using reversion and x-ray diffraction testing, an existing pre-orientation within the geogrid samples was shown to be due to orientation of the chain network.



reversion testing

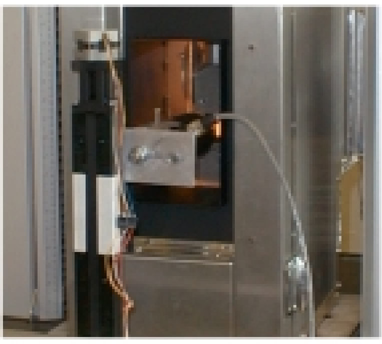
X-ray diffraction pattern

4. P. Caton-Rose, Finite Element Analysis of the Large Strain Deformation of Polymers, (2000) Ph.D. Thesis, Univeristy of Bradford

Thermal Effects

In addition to the existence of pre-orientation within the HDPE samples, it has also been demonstrated that significant effects occur due to changes in thermal conditions. These effects can be divided into two separate areas, heating due to deformation and changes in mechanical properties due to changes in temperature.

In order to evaluate these two effects the University of Bradford has constructed two custom designed test rigs using infra-red temperature measurement and cascade controlled temperatures.

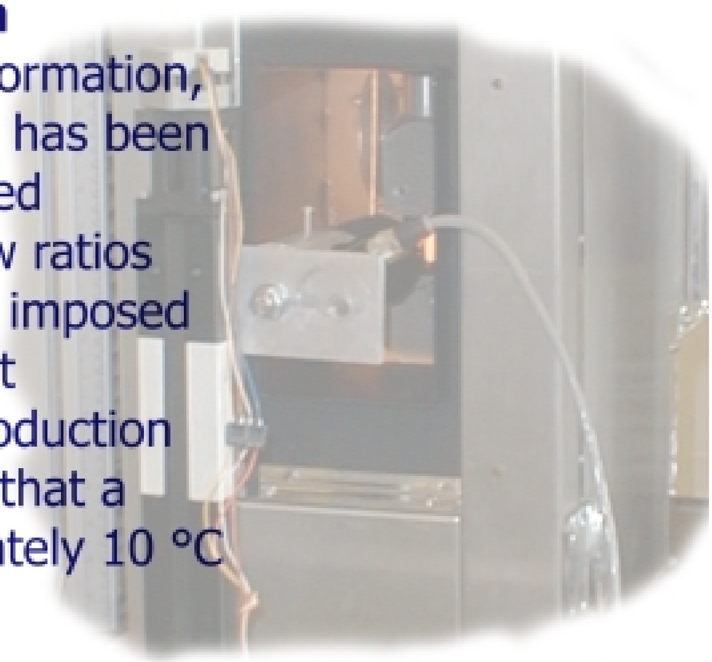


infra-red temperature measurement

cascade controlled constant width rig

Heating Due to Deformation

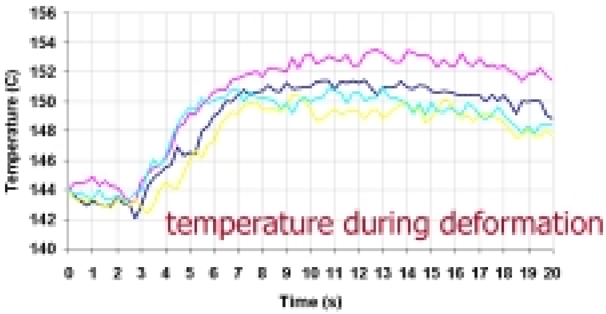
The surface heating, due to deformation, demonstrated by samples of PP has been measured using a Raytek infrared temperature sensor. Global draw ratios in the order of three have been imposed on a manufacturing geometry at temperatures approximating production conditions. The results showed that a sample can generate approximately 10 °C due to deformation alone.

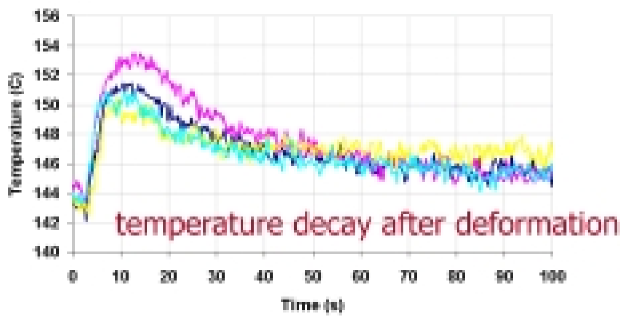


temperature measurement before necking

temperature measurement at initiation of necking

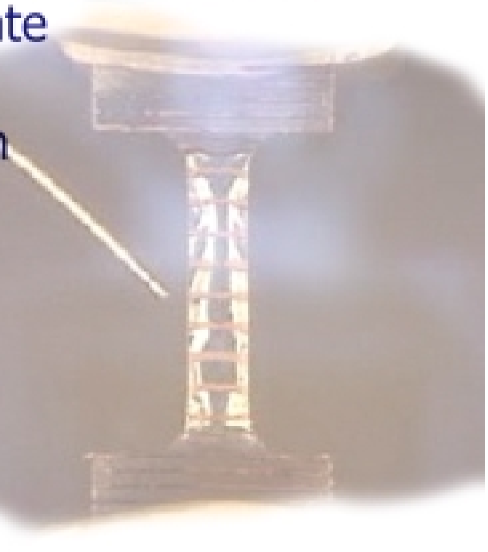
temperature measurement post necking

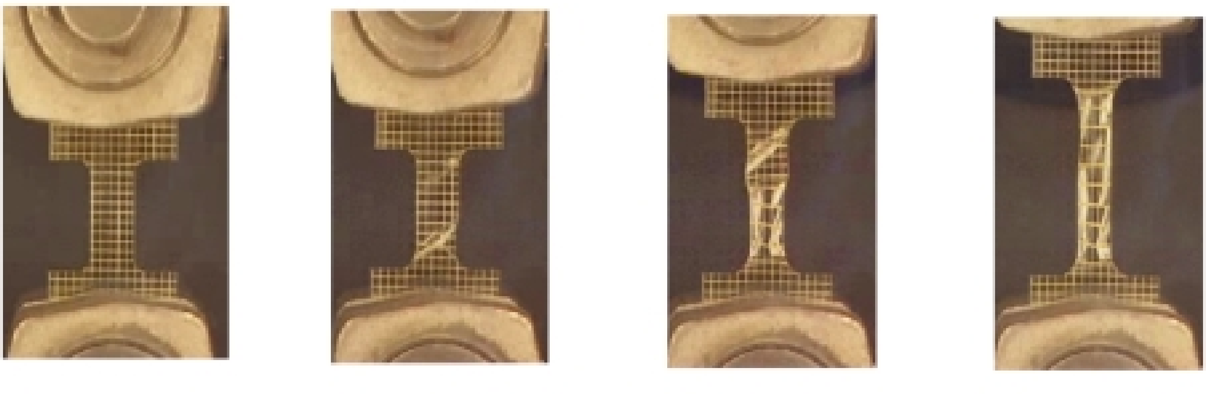




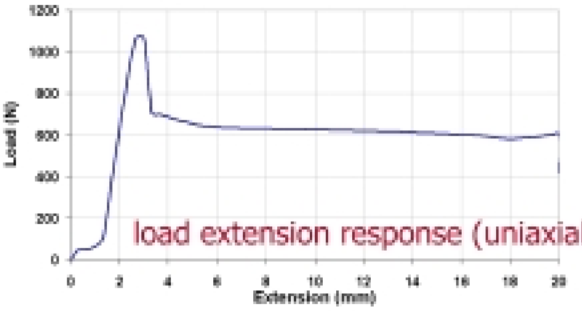
Temperature Dependant Mechanical Deformation

The mechanical properties of polycarbonate have been shown to be dependant on the temperature at which the deformation is imposed. In order to evaluate this effect a cascade controlled oven has been developed to measure the changes in mechanical properties at varrying temperature regimes. Results have been obtained for uniaxial and constant width deformation tests.

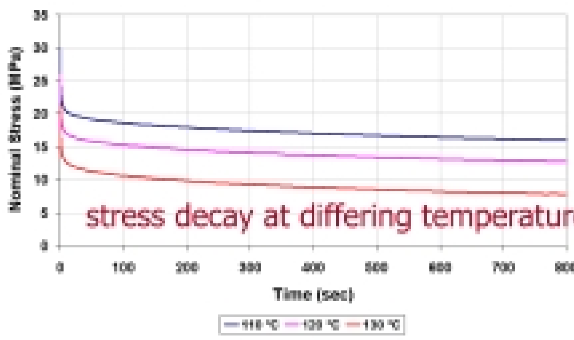




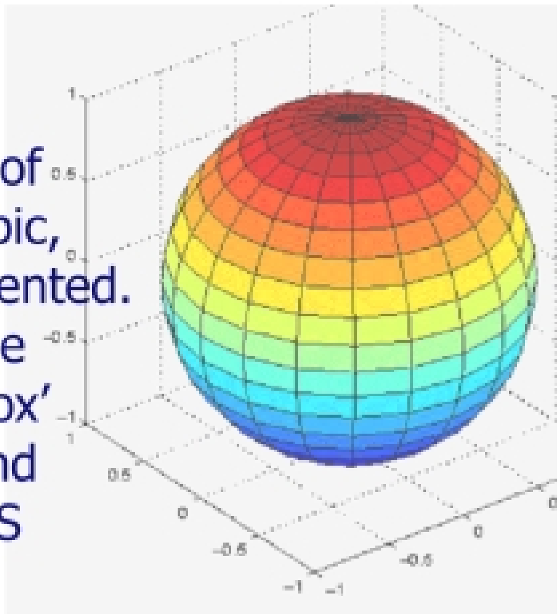
Uniaxial response to deformation including shear bands and necking



load extension response (uniaxial)



stress decay at differing temperatures

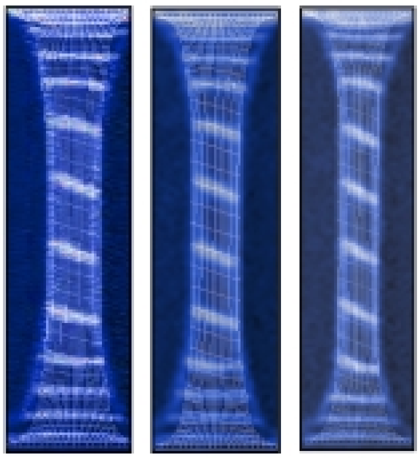


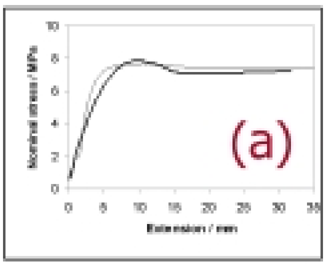
Pre-Orientation Analysis

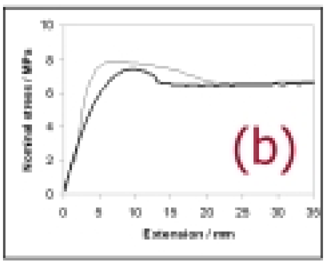
We assume that the material consists of a main network which is initially isotropic, plus a subnetwork which is initially oriented. The main network is represented by the nonlinear, rate-dependent 'sphere-in-box' model. The subnetwork is Gaussian, and prestrained by a deformation gradient S

The subnetwork is defined by the prestrain S, derived from shrinkage measurements, and the single parameter defining the number of crosslinks in the Gaussian network. The latter is derived from the differences in stress observed when stretching the extruded sheet along (a) and across (b) the extrusion direction. The bold lines are FE model predictions.

FE overlay on experimental images at 45° to extrusion direction





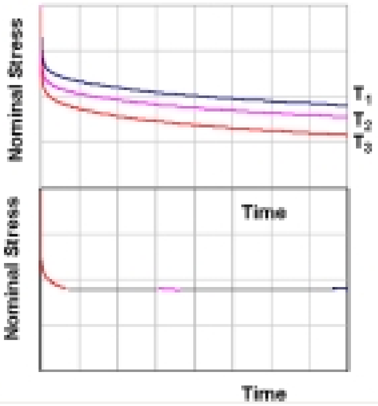


Non-Isothermal Mechanical Deformation

It has proved useful to model the stress relaxation for the constant temperature, uniform strain state using the Guiu-Pratt expression:

$$\sigma_R(0) - \sigma_R(t) = \frac{1}{V}\ln\left(1 + \frac{t}{c}\right)$$

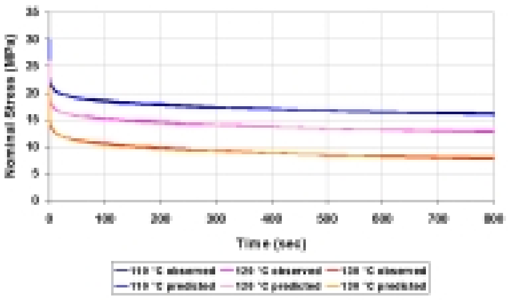
Iso-thermal stress relaxation data



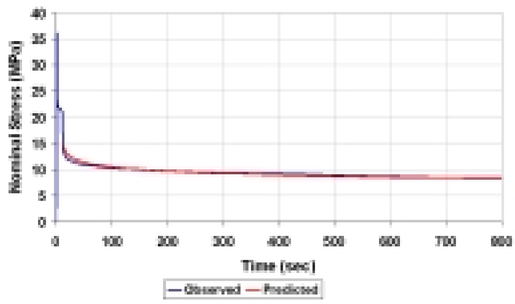
To predict this stress using the isothermal data, we have postulated that, when the temperature is varying, the stress decays at the same rate as would apply at the same temperature, strain and time after straining as for the isothermal case. This takes the form:

$$\sigma_R(t, T) = \sigma_R(0, T(0)) + \int_0^t \frac{\partial \sigma_R(\tau, T(\tau))}{\partial \tau} d\tau$$

Iso-thermal stress relaxation observed and predicted



Non-isothermal stress relaxation observed and predicted



Non-isothermal stress relaxation prediction error