Studying the Effects of Stress on the Material Properties of Graphite Moderators using Confocal Laser Microscopy

MANCHESTER 1824
The University of Manchester

Studying the Effects of Stress on the Material Properties of Graphite Moderators using Confocal Laser Microscopy

Joshua Taylor, Dr Graham Hall and Prof. Paul Mummery

Nuclear Graphite Research Group, The University of Manchester

Introduction

Graphite is used as a moderator in British Advanced Gas Cooled nuclear reactors due to its moderating efficiency, abundance and relative low cost.

Considerable stresses are generated in graphite components during reactor operation. These stresses can affect the ability of the reactor to cool the fuel and shut down by impeding the paths of the control rods. Therefore a detailed understanding of graphite's response to such stresses is required to ensure the safe and continued operation of the reactor.

Of particular interest are how stresses affect the pore structure and Young's modulus, as not only are these vital to the structural integrity of the material, but existing research into both these areas is lacking.

Laser confocal microscopy was used to study the microstructure at the surface of graphite samples during in-situ application of stress. By varying the levels of stress applied, changes to the microstructure of the materials were observed. By comparing the observed changes to the material with the quantitative stress-strain and deformation properties, it is possible to understand in detail graphite's response to stress.

Method

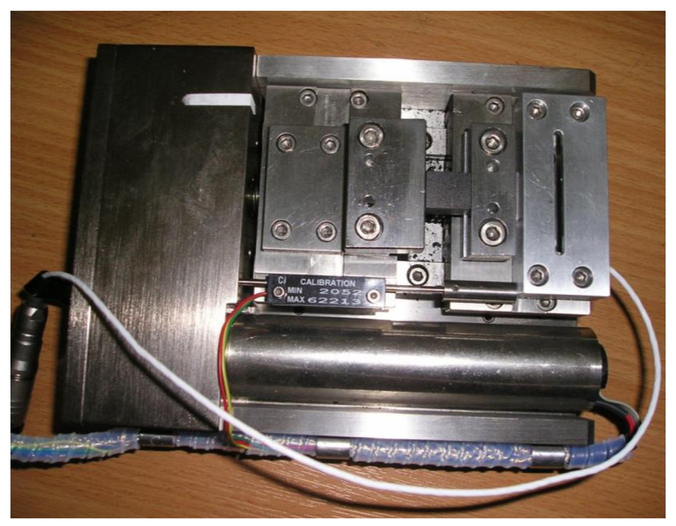
Gilsocarbon and Pile Grade A (PGA) graphite samples were machined to sizes of 1 cm^3. A confocal laser microscope was used to image samples during the application of stresses, allowing the surface profile of the material to be studied. Stress was applied axially using a compression rig.

The compression rig utilised integrated software to record the applied forces and the related contraction lengths. These data were used to determine how much stress was required to deform the samples, whether the deformation is recoverable and how much of it is recoverable.

By taking a series of images at varying levels of stress, changes to the open pore structure were observed.

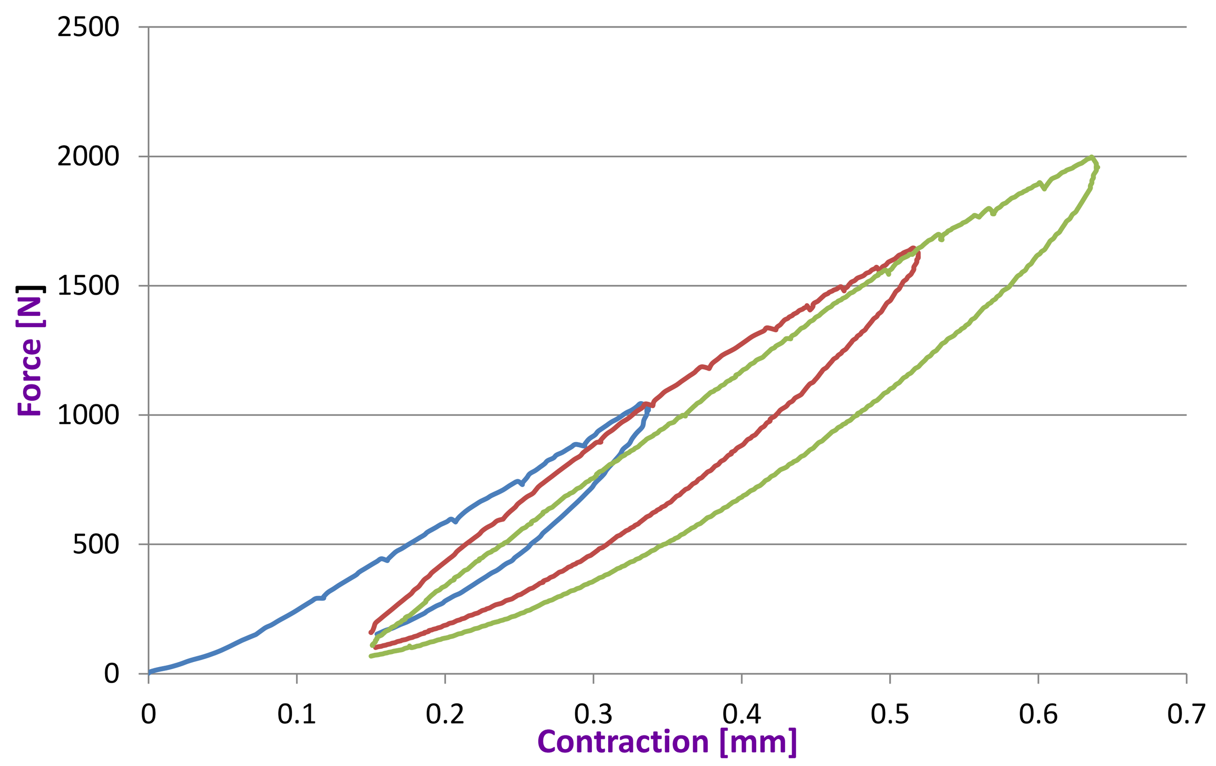
Left: The Confocal Laser Scanning Microscope used in the experiments.

Right: The axial compression rig compressing a graphite sample.



Results

British Pile Grade A (PGA) graphite was cyclically loaded and unloaded as shown in the graph below. PGA contains long, thin pores oriented in the direction of extrusion. Compression was applied **perpendicular** to the extrusion direction.



The graph on the left shows the compressive force applied against contraction length. Three separate loading-unloading cycles were performed, each reaching progressively higher loads.

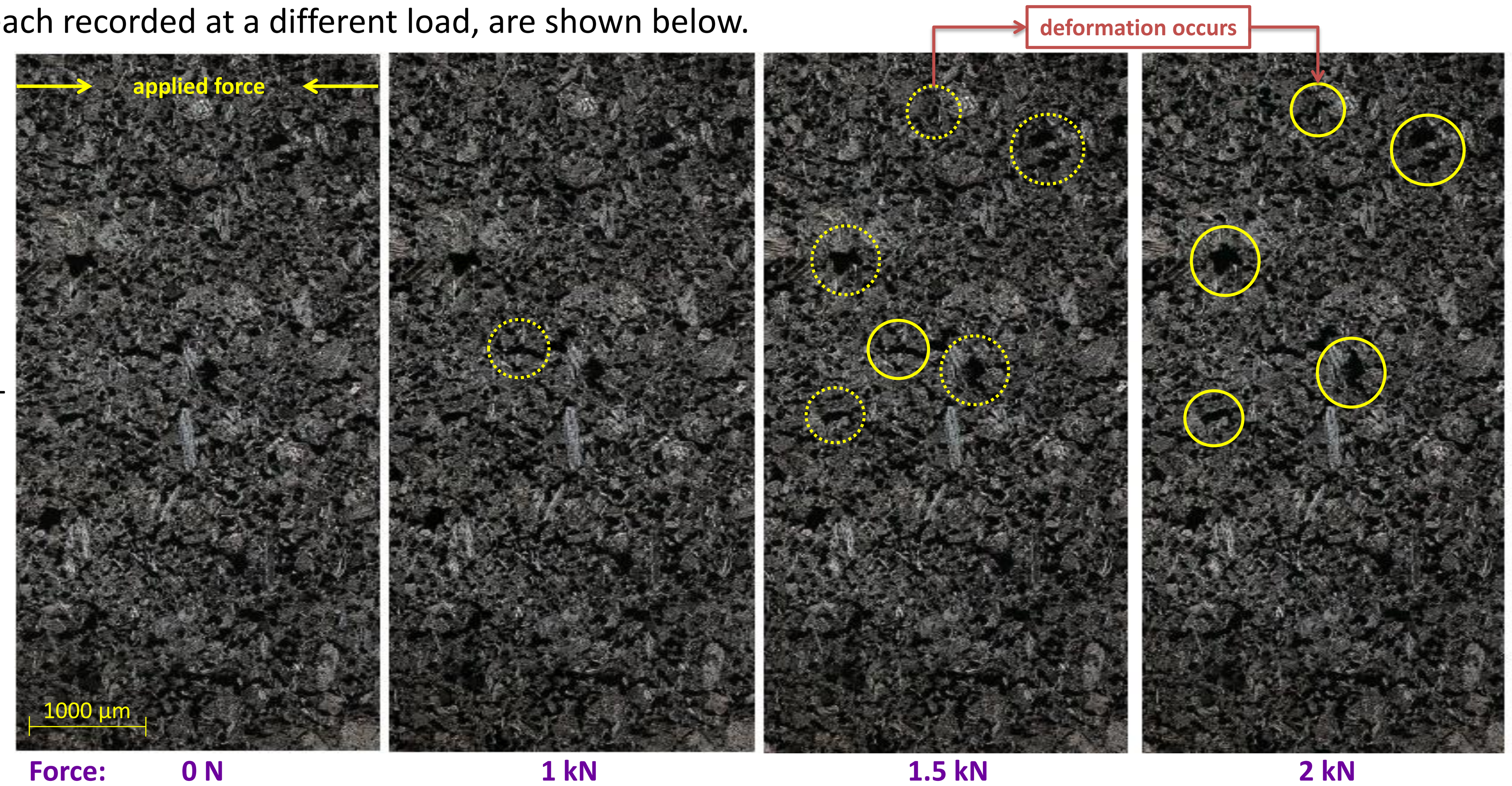
- The first loading-unloading cycle (blue) shows that application of low stresses cause some deformation that is not fully recoverable – permanent sample contraction.
- Subsequent cycles (red and green) show that contraction caused by higher stresses is fully recoverable.

By studying the micrographs at varying degrees of stress, it is possible to determine which components exhibit recoverable deformation and non-recoverable deformation. Four micrographs, each recorded at a different load, are shown below.

The images on the right show the sample contracting and deforming as a force is applied and removed. Yellow circles highlight regions where changes to the open pore structure (i.e. the black features) are clearly visible.

Few changes are visible at low stresses. As shown in the above graph, the contraction at low stresses is due to non-recoverable deformation. Some changes are, however, visible under the microscope at higher magnifications and were found to occur predominantly in the filler particles, collapsing in on themselves due to the applied load.

Deformation at higher stresses, shown to be fully recoverable, is at times visible using the microscope. The changes highlighted in yellow appear to be caused by opening of new pores or extension of existing porosity.



Pairs of dotted and full circles indicate regions where visible changes to the pore structure have occurred.

Conclusions

When PGA graphite is compressed perpendicular to the extrusion direction, damage to the microstructure can be split into two categories – recoverable and non-recoverable damage. Non-recoverable damage was found to occur in the filler particles, predominantly at low loads. At higher loads, the deformation was found to be recoverable, and beyond a specific threshold all sample contraction was found to repair itself upon removal of load. At high loads, much of the visible damage was caused by changes to the open pore structure.

Further Work

- Experimental method will be repeated with samples at different orientations with respect to the extrusion direction.
- Perform digital image correlation on pairs of images to determine where the strains are concentrated in the samples. From these strain maps the variation of local Young's moduli can be investigated.
- X-ray Tomography will be used for three-dimensional imaging of the interior of graphite; in particular the closed porosity.

Contact details: Joshua Taylor
E-mail: joshua.taylor@postgrad.manchester.ac.uk

School of Mechanical, Aerospace and Civil Engineering
Postgraduate Research Conference 2014