An Experimental and Computational Study of Plastic Deformation in Silicon Carbides

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Abstract

Silicon Carbide (SiC) belongs to a class of ceramics that have been used extensively in high temperature and/or high voltage applications. It's a popular semiconductor material and has also been used for ballistic protection. Interestingly, at high homologous temperatures, SiC is observed to deform plastically. At ambient temperature, failure is most often initiated by crack propagation. The failure strength of SiC is strongly dependent on the stress state, and lateral confinement plays a major role in damage evolution. In this work, both experimental and modelling methods were used to evaluate (plastic) deformation in SiC. Experiments with a wide range of loading rates were carried out for 6H-SiC, including quasi-static compression and high-strain rate compression with the use of a Split Hopkinson Pressure Bar (SHPB) apparatus. Quasi-static wedge indentation tests were also performed to understand the specifics of deformation mechanisms under a confined stress state in the macro-scale.

For load-controlled quasi-static compression tests, strain was measured using both strain gauges and the Digital Image Correlation (DIC) technique. Purely brittle behavior of the material was seen from the measured stress-strain responses, which was also confirmed by SEM/TEM examinations of fractured fragments. While stress-strain responses obtained from SHPB tests suggest the occurrence of plastic deformation under high strain rate loading conditions, with dislocations identified from TEM studies of fractured pieces. Wedge indentation experiments showed imprints on the indented surface as well as localised brittle fracture on the side surface. Post-experimentation SEM/TEM examinations show no clear evidence of dislocations for wedge indentation. In addition, two-dimensional (2D) discrete-dislocation-dynamics (DDD) modelling was conducted at microscopic scale to simulate plastic deformation of SiC micro-pillars under compression. Simulation results revealed the evolution of dislocations and associated plastic deformation behavior of the material at microscopic length scales. Plastic deformation was also rate dependent, and dislocations became more active with the increase of loading rate.

From our study we conclude that, under high loading rate or at microscopic scale, SiC can deform plastically, as evidenced by the development of non-linear stress-strain response and also the evolution of dislocations. These findings can be explored to control the brittle behaviour of the materials and benefit end users in relevant industries.

Keywords: Plastic deformation; Quasi-static compression; Split Hopkinson Pressure Bar; Wedge indentation; Discrete dislocation dynamics; Silicon carbides.

Acknowledgement: The work was funded by the Graduate School of Loughborough University, and forms part of a mini-CDT (Center for Doctoral Training) project, "Towards zero prototyping in ceramic component design" (2014~2017).