In-situ characterization of local fields in alumina using Raman and luminescence piezospectroscopy

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Abstract

Raman and luminescence spectroscopy can provide insights into the local stress or strain field within materials by tracking frequency shifts in their characteristic peaks. Raman scattering is sensitive to changes in lattice vibrations due to an applied strain, while luminescence is responsive to alterations in the electronic environment of specific atoms, providing information on interatomic distances and, consequently, applied strain. A key advantage of these techniques is their high spatial resolution, down to the micrometer scale, enabling precise mapping of local fields during in-situ micromechanical testing. It also appears as an alternative to Digital Image Correlation for materials deforming at small strain levels, such as ceramics. However, the main challenge lies in converting the measured peak shifts into meaningful stress or strain components.

Since the 1960s, both luminescence and Raman peak shifts have been studied in parallel for the corundum structure of α-alumina. Raman spectroscopy, in this context, generates seven independent peaks (1), which is particularly useful for determining the six independent components of the strain tensor. Despite this potential, Raman spectroscopy on alumina is challenging, and variability in peak shifts with strain has limited its widespread use for local field measurements. In contrast, luminescence spectroscopy offers rapid, reliable, and easily accessible peak shifts with respect to strain (2). However, with only two peaks available, luminescence provides less information about the local stress or strain tensor that have 6 components. Therefore, combining both techniques can leverage their respective strengths.

This work aims to compare various models from the literature that link luminescence (3) and Raman peak shifts (4) (5) to stress or strain, and to evaluate which models are most suitable for different use cases. Additionally, we explore how these models can be combined to maximize their effectiveness. These characterization techniques are then applied to fracture mechanics experiments to obtain accurate and localized stress field measurements. Specifically, a simulation-experimental approach is used to extract local stress fields from indirect in-situ measurements via peak shifts.

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