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# Deep Learning Mechanical Properties Classification of Metal-Ceramic Composites Using Nanoindentation Curves

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## Abstract

Metal-ceramic composites display a distinctive microstructure wherein the metallic matrix and ceramic particles are interpenetrated and partially interconnected. This microstructure enables the combination of the hardness and wear resistance of the ceramic phase with the toughness and ductility of the metallic matrix. As a consequence, these materials are highly effective in certain applications that require resilience under extreme mechanical and thermal conditions. These composites present a significant challenge, as their mechanical behaviour is dominated by intricate interactions between the phases, particularly in proximity to interfaces or regions containing subsurface features. High-speed nanoindentation represents an effective tool for probing interactions at the nanoscale and for creating detailed hardness and elastic modulus maps. However, the mechanical phase identification remains challenging due to averaging in interphase regions and the influence of subsurface features on property measurements, which complicate interpretation and correlation.

To address these challenges, in this work, the morphology of the nanoindentation curves of each constituent phase of the composite material is incorporated to train a deep learning model to obtain a good micromechanical classification of the material. Before training the model, the nanoindentation curves were carefully analyzed to understand their shape and behavior depending on the location of the indentation on the material's surface. This included examining areas influenced by subsurface features, which were revealed through cross-sectional cuts made using Focused Ion Beam (FIB) techniques.

Properly labeled curves are transformed into images using the Gramian Angular Field (GAF),

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which is a representation for encoding time series as images. A ResNet neural network, was trained to analyze these images and facilitate phase classification. The resulting comprehensive classification distinguishes each distinct phase without interference from others, phases influenced by neighboring regions, ideal interphase where both phases contribute equally, and data representing failures or defects.

This classification, which considers all relevant dimensions-surface location and subsurface features-facilitates a more profound comprehension of the composite's mechanical behavior. Moreover, the classifications are represented in a spatial context in X and Y coordinates, in conjunction with the classification of the indentation curves, thereby creating a comprehensive mechanical map that reveals the spatial distribution and interactions of the material's phases and interfaces. By addressing these complexities, this approach provides a powerful tool for studying complex composite systems, facilitating precise material design, and optimizing performance.