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Revisiting Classical Contact Mechanics through In Situ 3D X-ray Tomography and Digital Volume Correlation

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Abstract

Classical Hertzian contact theory has long served as the foundation for understanding the mechanics of elastic contacts. However, experimental validation of the full-field stress and strain distributions beneath the contact surface has remained a challenge, primarily due to limitations in in situ imaging techniques. In this study, we present a novel experimental approach that combines laboratory-based X-ray tomography with digital volume correlation (DVC) to achieve a three-dimensional characterization of the displacement, strain, and stress fields within a deforming elastomeric material during contact. Using a model system - a PDMS sphere indented into a PMMA plane - we capture the 3D displacement field within the PDMS sample during a normal indentation. This approach overcomes the constraints of traditional optical methods, which are limited to transparent materials and surface observations. By leveraging DVC, we extract the full-field displacement data and use it to drive finite element simulations, where boundary conditions are entirely derived from experimental measurements. This eliminates the need for numerical contact algorithms or assumptions, ensuring that the stress field is determined solely by empirical data. Our results provide the first experimentally driven characterization of the full-field stress distribution beneath the contact surface. While qualitative agreement with classical contact mechanics theory is observed, achieving quantitative comparison calls for the development of more sophisticated models and advancements in DVC regularization to account for surface-specific behaviors. This methodology is not limited to normal loading as it is fully adaptable to any contact scenario, including shear or mixed-mode loading. By bridging the gap between ex-perimental observations and theoretical predictions, our work paves the way for a deeper understanding of contact mechanics and the refinement of existing models.

Keywords:

Contact mechanics X-ray tomography Digital Volume Correlation (DVC) Full-field stress measurment Elastomeric materials