Abstract

Carbon nanotubes (CNTs), when used as reinforcement materials in nanocomposites, significantly enhance these overall properties. When combined with a suitable matrix, demonstrate superior performance compared to other nanocomposites. This improvement is primarily due to CNTs' high strength-to-weight ratio, excellent electrical conductivity, and outstanding thermal characteristics. Another advanced material of interest is functionally graded material (FGM). CNTs reinforced FGM—either through graded distribution of CNTs in the elasto-plastic material or uniform dispersion within the FGM matrix—are attracting substantial research focus. These materials offer promising possibilities for applications requiring gradual changes in material properties. While the use of CNTs as reinforcement is rapidly expanding across various industries, most research has focused on determining the mechanical properties of CNT-based nanocomposites through numerical, analytical, or experimental methods. Understanding contact behavior is crucial for CNT-based nanocomposite applications. Experimental challenges make finite element (FE) analysis a preferred approach. FE models simulate indentation and flattening contacts effectively. These simulations help predict contact performance in complex conditions. Such insights are valuable for optimizing industrial nanocomposite designs.

This study investigates both indentation and flattening contact behavior of CNT-based nanocomposites through single-asperity contact model. Contact analyses are performed for three types of material configurations: (1) CNTs uniformly distributed in an aluminum matrix composite, (2) graded distribution of CNTs within the homogeneous matrix, and (3) CNTs uniformly distributed in a functionally graded material (FGM) matrix composite (CNTR-FGMMC). The single-asperity contact models (Indentation and flattening) are developed in ANSYS using APDL code. During flattening and indentation, the summit (in flattening) and indenter (in indentation) are treated as rigid bodies, with downward displacement applied for loading and upward movement used to observe contact behavior through unloading.

To carry out the present simulations, several assumptions have been made regarding the interaction between the embedded CNTs and the surrounding matrix material. It is assumed that a perfect bond exists between the CNTs and the matrix, implying no interfacial slip. Additionally, a frictionless (full slip) contact condition is considered between the indenter/summit and the substrate to simplify the contact interaction. The contact behavior in the simulation is implemented using a pure Lagrange multiplier contact algorithm, ensuring accurate enforcement of contact constraints. To capture the onset of plastic deformation, the

von Mises yield criterion is employed, with the material's post-elastic response modeled using bilinear isotropic hardening. Model validation is achieved by comparing results with published literature, and convergence analyses are conducted to optimize computational time.
The preliminary analysis focuses on the effects of CNT thickness and radius within the CNT-reinforced Al matrix composite using indentation based contact model. Key contact parameters such as contact force, contact area, contact pressure, and deformation behavior are extracted by varying the wall thickness of CNTs. Detailed examination of these results reveals the presence of sink-in and pile-up behavior in specific cases and CNTs thickness affect significantly. The flattening action is simulated using a rigid flat. It is observed that beyond a certain CNT thickness, an increase in volume fraction of CNTs enhances both the contact force and contact area. Furthermore, a higher percentage of CNTs causes more matrix material within the asperity to yield plastically.

The present work also explores the spherical indentation contact behavior of a functionally graded CNT reinforced composite (FG-CNTRC) substrate. The composite gradation is achieved by varying the distribution of CNTs within the aluminium matrix. A comprehensive investigation is performed for three CNT distribution types—uniform, increasing, and decreasing with depth—to assess their influence on various contact parameters. This study aims to assist in the modeling and fabrication of FG-CNTRC substrates tailored for specific and damage-resistant contact performance.

The study extends to simulate the flattening contact of a CNT-reinforced functionally graded material (CNTR-FGMMC) using a finite element-based cylindrical model. This analysis emphasizes the impact of matrix gradation index, modeled as an elastically graded material where the modulus of elasticity and tangent modulus vary while yield strength remains constant. The flattening simulations are performed by varying the elastic inhomogeneity while keeping the CNT wall thickness constant. The results demonstrate how changes in the gradation parameter significantly affect contact behaviour of the composite. To further explore the indentation contact behavior of CNTR-FGMMC, a 3D finite element model is developed using APDL in ANSYS. Results show that positive gradation improves both contact force and contact area when compared with other graded and without graded systems, although it demonstrates a higher force but lower area when compared to the only matrix material. These findings offer critical insights for designing nanocomposites with specific performance goals.