Abstract

Metal matrix composites (MMCs) combine the beneficial properties of alloys and reinforcement materials, resulting in enhanced tensile strength and tribological performance at elevated temperatures. This research examines the fabrication of multi-walled carbon nanotube (MWCNT)-reinforced Inconel 718 composites via laser directed energy deposition (LDED). While LDED demonstrates considerable promise for producing advanced MMCs, achieving high powder catchment efficiency (PCE) alongside acceptable dilution (D%) and aspect ratio (AR) remains a significant challenge. To address this, a machine learning (ML)-based optimization framework was implemented to determine laser processing parameters that maximize PCE without compromising D% and AR. A systematic methodology was then established to generate uniformly dispersed MWCNT/Inconel 718 composite powders suitable for LDED. This methodology incorporated optimized surface functionalization of MWCNTs to minimize agglomeration, followed by high-energy ball milling (HEBM) to improve dispersion within the Inconel 718 powder. The MWCNTs underwent a two-step chemical functionalization: (i) magnetic stirring in a 3:1 H_2SO_4 and HNO_3 solution at two acid concentrations (3 M and 8 M), and (ii) ultrasonic treatment in H_2O_2 solution. Of the six functionalization protocols evaluated, the process involving 4 hours of magnetic stirring followed by 2 hours of sonication was optimal, achieving a high degree of functional group attachment (11.47%) with reduced surface defects and consistent mixing. Using these optimized conditions, MWCNT/Inconel 718 composite powders with 0.5 wt.%, 1 wt.%, 1.5 wt.%, and 2 wt.% reinforcement were synthesized and used to deposit coatings under the optimized laser parameters. Portions of the deposited samples were heat-treated. Reciprocating wear tests were conducted on both as-built and heat-treated specimens at room temperature and 450 °C. In as-built samples, the specific wear rate decreased under both testing conditions, attributed to increased surface hardness and the lubricating effect of MWCNTs. Notably, microhardness and wear resistance improved significantly after heat-treatment for MMCs containing 0.5 wt.% MWCNTs. However, coatings with greater than 0.5 wt.% MWCNTs exhibited reduced hardness and wear resistance post-heat-treatment, due to excessive NbC precipitation, which inhibited γ'' formation. Subsequently, bulk samples of Inconel 718 and composites with 0.5 wt.% and 1 wt.% MWCNTs were fabricated and heat-treated. Tensile testing at room temperature, 500 °C, and 700 °C demonstrated substantial improvements in tensile properties for the heat-treated 0.5 wt.% MWCNT/Inconel 718 composite, with the benefits becoming more pronounced at higher temperatures. In summary, the systematic optimization of laser processing and powder-mixing strategies for MWCNT-MMCs resulted in significant improvements in the high-temperature mechanical properties of both coatings and bulk samples.

Keywords*: Metal Matrix Composites (MMCs), Multi-walled carbon nanotubes (MWCNTs), Inconel 718, Surface functionalization, Laser Directed Energy Deposition (LDED)*