Abstract

In the pursuit of advancing aerospace technology, one of the most enduring challenges remains the high cost of space exploration. The Space Shuttle era demonstrated the potential of reusable launch systems to reduce expenses, but technological constraints have consistently impeded their widespread adoption. A critical component in this context is the rocket nozzle, which is subjected to extreme thermal and mechanical stresses due to intense heat and pressure, leading to substantial material degradation over time. When conventional heat management strategies fall short, materials with ultra-high melting points, such as molybdenum and Ni-based super alloys, are typically employed. However, despite their excellent high-temperature strength and oxidation resistance, these materials exhibit relatively low thermal conductivity and present significant challenges in terms of manufacturability and cost. Such limitations can reduce their effectiveness in actively cooled rocket nozzle applications, where efficient heat transfer and thermal management are critical design requirements. In response, copper-based alloys have emerged as promising alternatives, offering a favourable balance between strength and thermoelectrical performances. Early developments included alloys like NARloy-Z (Cu-Ag-Zr) and GlidCop-A115 (Cu with ~0.15 wt% Al_2O_3). More recent research has focused on copper-chromium systems, particularly those alloyed with elements such as niobium, zirconium, or silver. These additions improve mechanical performance through precipitation strengthening, leveraging the low solubility of the alloying elements to form stable intermetallic precipitates. This approach maintains a high-purity copper matrix, preserving its excellent thermal and electrical conductivity over a wide temperature range. To further enhance the solubility and distribution of these elements, rapid solidification techniques are essential. These approaches are directed in forming a supersaturated solid solution that promote uniform precipitation during subsequent thermal treatments. In this context, metal Additive Manufacturing (AM) technologies such as Direct Energy Deposition (DED) and Laser Powder Bed Fusion (L-PBF) offer a transformative pathway for future alloy development. Their ability to achieve localized cooling rates on the order of 10^5–10^6 K/s enables microstructural control that was previously unattainable using conventional techniques. By integrating advanced alloy design with cutting-edge additive manufacturing, this approach holds significant promise for producing high-performance rocket nozzle materials that meet the rigorous demands of modern aerospace propulsion, paving the way for more sustainable space exploration.