

Abstract

Inconel 718 (IN718) superalloy is extensively employed in aerospace, power generation, and marine applications owing to its excellent high-temperature strength; however, its surface performance under severe oxidation, corrosion, and wear environments remains a limiting factor. The present thesis investigates the development of nanocrystalline CoNiCrAlY-based surface modifications on IN718 using advanced coating and surface engineering techniques, namely High Velocity Oxygen Fuel (HVOF) spraying, Air Plasma Spraying (APS), and Laser Surface Alloying (LSA), with the objective of enhancing high-temperature oxidation resistance, aqueous corrosion resistance, and wear performance. CoNiCrAlY was selected as the coating and alloying material due to its ability to form stable and adherent Thermally Grown Oxide (TGO) layers, predominantly α -Al₂O₃, which significantly improve oxidation resistance, corrosion protection, and tribological behaviour.

Nanocrystallization of CoNiCrAlY powder was achieved through high-energy mechanical milling, and the influence of milling parameters and Process Control Agents (PCA) on powder characteristics and flowability was systematically investigated. Mechanical milling was carried out in a planetary ball mill using tungsten carbide media at 300 rpm with a ball-to-powder ratio of 10:1, employing stearic acid and toluene as PCAs for milling durations ranging from 10 h to 36 h. The milled powders were characterized using Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), X-ray Photoelectron Spectroscopy (XPS), and Differential Scanning Calorimetry (DSC), while flowability was assessed using the Hausner ratio. Milling resulted in significant crystallite refinement from ~147 nm to below 10 nm, accompanied by pronounced particle morphology evolution and PCA-dependent agglomeration behaviour. Toluene promoted continuous particle size reduction, whereas prolonged milling in stearic acid led to partial re-agglomeration. Based on crystallite size, morphology, and flowability considerations, powders milled for 10 h and 25 h in stearic acid as PCA were selected for subsequent coating and alloying studies.

HVOF coatings of unmilled and milled CoNiCrAlY were deposited on IN718 substrates to evaluate the influence of powder milling on coating microstructure, residual stress, oxidation behaviour, corrosion rate, and wear resistance. The HVOF-sprayed coatings exhibited dense microstructures consisting of γ/γ' and β phases, with a systematic decrease in β -phase fraction and an increase in alumina content with increasing milling time. The coatings developed predominantly compressive residual stresses ranging from -395 to -525 MPa, with higher

magnitudes observed for coatings deposited using milled powders. Isothermal oxidation studies conducted between 800 °C and 1000 °C for exposure times up to 100 h demonstrated enhanced oxidation resistance for coatings deposited from milled powders, reflected by increased activation energies (163-211 kJ/mol) and the formation of continuous, alumina-rich TGO layers. A significant improvement in corrosion resistance was observed, with corrosion rates decreasing from 5.24 µm/year for unmilled coatings to 0.39 µm/year for coatings deposited using milled powders. Wear resistance also improved by approximately two orders of magnitude for HVOF coatings produced from nanocrystalline feedstock.

APS coatings were developed using unmilled and milled CoNiCrAlY powders to further assess the effect of feedstock nanocrystallisation. Comprehensive characterization revealed that coating density increased from 6.2 g/cm³ to 6.89 g/cm³ by 11.13 % with increasing milling time. The APS coatings consisted of γ , γ' , and β phases with characteristic inter-splat boundaries and porosity, while phase fractions were strongly dependent on milling duration. Isothermal oxidation studies showed that coatings deposited from 25 h milled powders formed predominantly alumina-based TGO layers, whereas coatings from unmilled and 10 h milled powders formed mixed spinel oxides. Wear studies indicated superior wear resistance for APS coatings deposited using unmilled powder due to higher hardness associated with greater lattice strain, while aqueous corrosion resistance was highest for coatings deposited using 25 h milled powder.

LSA of CoNiCrAlY on IN718 was performed to achieve metallurgically bonded surface layers. Laser parameters were optimized within a power range of 800-1800 W and scan speeds of 25-50 mm/s, with an optimum condition identified at 1400 W and 50 mm/s. Laser alloying using milled powders produced refined and homogeneous alloyed zones with enhanced solute distribution, favourable crystallographic texture, and improved mechanical properties. Microstructural analysis revealed partial surface segregation of alumina with increasing milling time, leading to reduced aluminium content in the alloyed matrix. Comparative studies involving as-received IN718, laser-melted IN718, and laser-alloyed samples showed that unmilled powder alloyed layers exhibited superior oxidation resistance due to higher aluminium content in the matrix, whereas aqueous corrosion and wear resistance were highest for alloyed layers produced using milled powders due to the uniform distribution of nano-alumina particles and smaller crystallite size.

Overall, laser alloying using unmilled CoNiCrAlY powder exhibited superior isothermal oxidation resistance compared to HVOF- and APS-deposited coatings due to denser microstructure, although the resulting TGO contained a greater fraction of mixed oxides,

increasing spallation susceptibility. In contrast, laser-alloyed surfaces produced using milled powder showed the highest aqueous corrosion resistance owing to the uniform distribution of nano-alumina particles. The highest wear resistance was achieved in HVOF coatings deposited using nanocrystalline CoNiCrAlY powder, attributed to the retention of refined powder characteristics and dense coating microstructures. Collectively, this study demonstrates that controlled nano-crystallization of CoNiCrAlY powder, combined with optimized thermal spray and laser alloying techniques, enables tailored surface properties and establishes clear process-structure-property relationships for enhancing the service life of IN718 in high-temperature and aggressive environments.

Keywords: Inconel 718, Nanostructured Coating, Thermal Spraying, HVOF, APS, LSA, Corrosion Study, High Temperature Oxidation, Wear, Microstructure, Microhardness, Nanoindentation, Residual Stress