ABSTRACT

In this Ph.D. thesis work, Fe-based amorphous/ nanocrystalline coatings were synthesized using two different low chromium containing compositions of $Fe_{73}Cr_2Si_{11}B_{11}C_3$, at. % (Powder-1) and $Fe_{63}Cr_9B_{16}C_7P_5$, at. % (Powder-2) via atmospheric plasma spraying at different plasma spraying parameters (plasma power and spray duration) to vary the heat input. The influence of spraying parameters and subsequent variation in degree of melting on resulting microstructural evolution and subsequent effect on mechanical (hardness and wear) and corrosion properties of the coatings have been studied extensively. Microstructural studies demonstrated that porosity content and fraction of crystalline phase formation in the coatings were highly sensitive to spraying parameters. Increase in both the plasma power and spray duration (i.e. coating thickness) led to reduction in the porosity content and higher devitrification. The retained/formation of amorphous phase in the coatings was attributable to the high glass forming ability of the feedstock powders and extremely high cooling rate associated with plasma spraying technique.

Improving mechanical (hardness and wear) properties and meanwhile maintaining excellent corrosion resistance in plasma sprayed amorphous/ nanocrystalline coating is challenging because of the conflicting role of crystallization on wear and corrosion resistance. Therefore, optimization of the process parameters was done and both Powder-1 and Powder-2 based coatings deposited at optimum spraying parameters exhibited improved wear as well as corrosion resistance, ascribed to a better combination of porosity and amorphous content. Powder-2 based coating synthesized at optimum parameters exhibited better wear and corrosion resistance than that of Powder-1 based coating, ascribed to denser microstructure (porosity ~ 3.3%), presence of higher amorphous phase (~ 84.2 %) and formation of protective compounds (α-FeOOH and $Fe_{2-x}Cr_xO_3$). Powder-2 based coating deposited at optimized parameters showed nanohardness value of 10.5 GPa, wear rate of 4.1×10^{-6} mm^3/Nm and corrosion current density of 4 μA/cm^2. This indicates that Powder-2 based coating synthesized at optimized parameters could be a good alternative for industrial applications due to higher wear and corrosion resistance.

Besides, nanomechanical deformation behavior in Powder-2 based amorphous/ nanocrystalline coating synthesized at optimum spray parameters has been investigated via multi-scale nanoindentation and nanoscratch. Nanoindentation test revealed that plastic flow of the coating displayed conspicuous “pop-in” events arising from shear band formation at lower loading rate, which gradually disappeared with increasing loading rates, implying strong loading rate sensitivity of the coating. Coating also displayed a significant indentation size effect (ISE) as hardness decreased with increasing applied indentation load, ascribed to the formation of higher mount of free volume at higher load which leads to strain softening, as a result, hardness decreases. Deformation response in a tribological contact was evaluated by nanoscratch test. Serrations in coefficient of friction and lateral force curves indicated the formation of shear bands during low load (5000 μN) nanoscratch, and two different types of prominent shear bands were observed near the scratch track in case of high load (5 N) nanoscratch. These observations elucidated that plastic strain in the coating generated during the scratching process was accommodated by shear band formation.

Further, multi-scale room temperature creep behavior of Powder-2 amorphous/ nanocrystalline coatings deposited at varying plasma power has been investigated. Micro- and nano-indentation testing at different loading scales was carried out to reveal the combined effect of microstructural heterogeneities viz. porosity and constituent phases, as well as the individual contribution of amorphous and crystalline phases on the creep behavior of the coatings. Microindentation creep tests revealed higher creep resistance for the coating deposited at elevated power, ascribed to lower porosity and higher degree of crystallinity. Nanoindentation creep tests showed that mixed (amorphous and intermetallic) phase possessed lower creep displacement and retardation spectra compared to fully amorphous one, indicating better creep resistance.

Keywords: Fe-based amorphous/ nanocrystalline coatings; Atmospheric plasma spraying; Nano- and micro-scale structural evolution; Multi-scale indentation and tribology; Shear band activity; Potentiodynamic polarization; Electrochemical impedance spectroscopic study; Multi-scale room temperature creep