MICROSTRUCTURAL, MECHANICAL AND THERMAL STUDIES OF ANODIC COATING ON ADDITIVELY MANUFACTURED Al-10Si-Mg ALLOY FOR SPACECRAFT APPLICATIONS

Abstract

The growing interest in using additively manufactured (AM) Al-10Si-Mg alloy for spacecraft thermal control components, such as electronic housings, antenna feeds, waveguides, structural brackets, collimators, and thermal radiators, combined with the limited literature on anodization of this alloy, highlights the necessity for further research. This thesis explores the development of the anodization process, detailed anodic coating characterizations (microstructural, nanomechanical and thermal), and performance evaluation with respect to space qualification tests. The anodic coating was developed on 3D printed Al-10Si-Mg alloy by sulphuric acid-based anodization technique at low (~9 °C) temperature for the first time. The microstructural and surface properties of the coating were investigated. The near-surface elemental/electronic structure and chemical nature of the anodic coating were also analyzed. The nanoindentation technique was employed to evaluate the hardness and modulus of the coating across plan- and cross-sections. The anodic coating shows superior hardness and modulus as compared to reported literature values, possibly due to dense microstructure and the presence of harder ceramic phases. However, the hardness and the modulus values differ with respect to plan- and the cross-section due to varying microstructural features. A novel methodology combining nanoindentation experiments and finite element (FE) analysis was successfully utilized to achieve a stress-strain relationship of the anodized surface of AM Al-10Si-Mg alloy for both the plan- and cross-sections. The elasto-plastic properties (yield strength, σ_y, and strain hardening exponent, n) of the anodic coating were quantified as (1200 MPa, 0.12) and (1900 MPa, 0.07) for plan and cross-sections, respectively.

In this thesis, Artificial Neural Network (ANN) and the Power law-based models were developed from experimental nanoindentation data for predicting the elastic modulus and hardness of anodic coating on AM Al-10Si-Mg at any desired loads. The predicted curves were utilized for evaluating the normalized hardness and modulus of the coating, and were compared with conventionally used statistical tools, e.g., Weibull analysis.

The thermal characteristics of the anodic coating were also evaluated for varying heat loads from internal heat-dissipating packages and external loads, e.g., solar, earth shine, and albedo

loads. The thermal stability of the coating was characterized by the differential scanning calorimetry (DSC) technique, indicating no visible transitions across the spectra. The variation of infrared emittance of the coating as a function of temperature was also investigated using the calorimetric method. Further thermal design and analysis through FE simulation of the anodic coated surface was carried out with the help of Spacecraft Thermal Analysis (STA) software.

The thermo-optical properties (solar absorptance-α_s and infrared emittance-ε_{IR}) of the coating as a function of wavelength were evaluated in the range 200-2500 nm and 3-30 µm, respectively. Finally, these properties were not altered after the space environmental tests (thermal shock cycling, thermo-vacuum, and relative humidity). Furthermore, the corrosion resistance improved significantly after anodization of the AM alloy due to the dense microstructure.

In summary, the thorough evaluations pertaining to microstructural, mechanical and thermal studies of anodic coating on additively manufactured or 3D printed Al-10Si-Mg alloy for spacecraft applications were conducted successfully. The results from this thesis would contribute immensely to the surface engineering of additively manufactured Al-10Si-Mg alloy, pertaining to other types of conversion coatings on AM Al-10Si-Mg alloy and its variants.

Keywords: *Anodization; 3D printed Al-10Si-Mg; Emittance; Nanoindentation; Corrosion; Space qualification; artificial neural network (ANN); Finite element (FE) modelling.*