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Thesis Title: Material and Mechanical Aspects of Thin Film Coatings for Strain Sensing Application on Aero Engines

# SYNOPSIS

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Aero engines are one of the most complex machines on this planet and have propelled the necessity of advanced material technologies. Health monitoring of the engine is performed by a variety of sensors and amongst these strain sensor is very important as it aids in evaluating the stresses experienced by the body. Unlike conventional foil gauge which tends to debond under hostile environments in the engine like high rpm of blades, temperature, mass flow, etc, thin film based strain gauges are likely to exhibit better adhesion on the substrates.

The usage of Ni-Cr thin films in strain gauge sensor has been proven for static application, wherein the substrate does not experience the fluctuating loads. Material and mechanical aspects of thin films for design and development of thin film based strain gauge sensor for aero engine application was taken up as a research work. One of the objectives of the work was to characterize the Ni-Cr thin films with varying composition deposited by sputter deposition process and characterize the films for its microstructural features and mechanical properties. The correlation of these properties is performed and amongst the film compositions investigated the film with alloy composition of Ni-Cr:80-20 at% exhibits the most distinct columnar structure, highest electrical resistivity (2.037 μΩm), hardness (5.8 GPa) and the modulus (180 GPa). This Ni-Cr: 80-20 at% film exhibits no surface cracks when loaded in the elastic region of the titanium alloy GTM-Ti-64.

Resistance to deformation under the action of externally applied load on a body results in stress within the body. In single or multilayer film stacking the stress experienced in the film by virtue of substrate deformation needs to be investigated quantitatively. The substrate stresses are transferred to the films by shear stresses at the interface. In order to measure the surface strain by change in the electrical resistance of the gage it is important to quantitatively evaluate the stresses in the films. Are these stresses very high to cause delamination and film cracking or are these stresses too less to be measured. In order to understand the stress evolution and transfer mechanism, an analytical approach, numerical simulation and experimental validation were performed.

Thin film strain gauge device architecture has been engineered such that an insulating layer of alumina is deposited on substrate and a sensing layer is deposited on the insulating layer to avoid thermal mismatch and maintain the strain compatibility. A alumina of 45 micron thick alumina layer was successfully deposited on Titanium alloy (GTM-Ti-64) by sputter deposition without any edge delamination and microcracks. Finite Element Analysis (FEA) results showed that the axial and shear stress profiles at the Ti alloy-alumina interfaces for both single and multilayer architecture are similar and higher when compared with the stresses in alumina-NiCr. The shear stress profile for single layer and multilayer architecture follows the modified shear lag model with peak shear stresses at the extremes and peak axial stress at the centre of the film. The axial stresses in the alumina film is found to be significant in both FEA and validated by experimental findings with film fracture strength of 814 MPa. Similarly, the shear stresses were found to be minimal by FEA studies and the experimental finding suggests the film fracture under tensile mode.

Complete strain transfer was observed from substrate to these thin films under both tensile and vibratory fatigue, suggesting proper adhesion of the alumina film on the Ti alloy substrate. The maximum strain compatibility of thin film alumina on Ti alloy substrate was found to be 0.22 %. A Goodman correction for the fatigue data under axial mode was performed and on combining the entire fatigue data for $R = -1$ linear fit was observed across all the data points wherein the Basquin equation was considered for data analysis and the fatigue strength coefficient and exponent are found to be 872.56 and -0.054 for alumina thin film on Ti alloy substrate.

Thin film strain gauges (TFSG) with these characteristics were deposited on the compressor rotor blade of one of the typical aero engines. Thick contact pads and a new bonding technique are used for taking the lead wires. The entire multilayer structure with wire bonding was tested under static and dynamic (vibratory fatigue) conditions and TFSG exhibited a reproducible strain when compared against foil based strain gauge under both tension and compression. TFSG device was tested for a duration of 2200 seconds with a blade vibration frequency of 406 Hz i.e. $8.9x10^5$ cycles. During the entire test duration, TFSG successfully measured strains from the aero engine blade.