ME – PhD Thesis Colloquium

Synthesis, Mechanical Characterisation, and Tribological Performance of Nanoporous Alumina Layer on 6061 Aluminium Alloy

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ABSTRACT

Nanoporous alumina (NPA) is a nanostructured thin-film material formed through the electrochemical anodization of aluminium. Under controlled two-step anodization, ultrapure aluminium yields a highly ordered nanoporous oxide layer that serves as a template for the synthesis of nanostructures such as nanowires, nanotubes, and nanocomposites. When embedded with copper nanowires, this architecture can function as a composite coating for tribological applications. In this work, the anodization process is adapted to commercial-grade aluminium alloy Al6061, addressing the limitations of ultrapure aluminium in practical engineering contexts. The process parameters were systematically varied to study their influence on the geometry of the NPA layer, using electron microscopy and electrochemical characterization. The mechanical properties, specifically the hardness of the layer as a function of pore size and thickness of the layer, were determined through micro-indentation hardness tests.

Dynamic mechanical behaviour of the NPA layer in Al6061 was experimentally studied using low-velocity impact tests of a rigid ball against the porous layer. Normal impact tests were conducted to examine the response of the layer to impact loading, serving as a complement to the quasi-static indentation studies. Oblique impact tests, which impose combined normal and shear loading, were performed to assess the influence of friction on the deformation of the nanoporous layer as well as on the rebound dynamics of the impacting body.

An elasto-plastic model based on contact stiffness was developed and applied to describe the low-velocity normal impact phenomena, which can estimate the coefficient of restitution as a function of the material properties (elastic modulus and hardness) and geometric properties (crater radius and size of ball) of the impacting bodies. An extension of the model to predict the transition of the impacting ball from sliding to pure rolling during contact in an oblique impact event was developed and experimentally verified. Energy dissipation associated with plastic deformation and crack formation was quantified by analysing impact crater size, crack density, and coefficient of restitution using microscopy and image-processing techniques.

The tribological performance of the nanoporous alumina layer, particularly its wear resistance, was evaluated using reciprocating wear tests conducted under both dry and lubricated conditions. The nanoporous coating exhibited significantly enhanced wear resistance and an extended wear life compared to the uncoated aluminium alloy. A dedicated experimental test rig was designed and developed to perform in situ indentation and reciprocating shear tests of the nanoporous layer inside a scanning electron microscope. Preliminary experiments using this setup were carried out to study the damage mechanism of the porous layer under combined indentation and shear loading conditions. We demonstrate that the uniform porous architecture of the NPA layer enhances damage tolerance by localizing deformation, thereby mitigating coating delamination and spalling while suppressing catastrophic failure of the hard and tough NPA layer under both normal and frictional loads.

ABOUT THE SPEAKER

Gautam Revankar A is a Ph.D. student in the Department of Mechanical Engineering working with Prof. M S Bobji at the Indian Institute of Science (IISc) Bengaluru. He graduated with a B.E. in Mechanical Engineering from B.M.S. College of Engineering (Bengaluru) and an M.Tech in Materials Science and Technology from the Indian Institute of Space Science and Technology (Thiruvananthapuram). His research interests include tribology, materials science, and electrochemistry, among others. Beyond research, he is actively involved in science outreach activities in rural schools.