

## MULTIPLE CRACKING EVENTS IN METAL BI-LAYERS ON POLYMER SUBSTRATES

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Metal films on polymer substrates are used in a variety of applications such as flexible electronics, sensors, medical devices and aerospace including multilayer insulators and surface mirrors on satellites. A common way to assess the mechanical behavior of metal-polymer systems is with fragmentation testing, which strains the system under uniaxial tension. During straining cracks or localized deformation (necks) develop perpendicular to the loading direction and buckle delaminations occur parallel to the loading. From the crack spacing the fracture behavior can be determined and the interface adhesion energy can be measured from the buckles. Fragmentation testing has been used on single and multilayer films and has shown that brittle adhesion layers next to the substrate, can cause brittle cracking of normally ductile overlying films. A similar fracture behavior was observed here for the Inconel-Ag-Teflon system, but in this system, the top 30 nm Inconel film is the brittle layer inducing brittle cracking of the underlying 150 nm Ag film. Inconel acts as a corrosion protection for the Ag layer in surface mirrors on satellites in low earth orbit, where the material should not develop cracks upon mechanical loading. Observation of the Inconel surface during in-situ tensile straining revealed crack formation in the Inconel layer at less than 1% strain, which continues with increasing strain (primary cracks). At approximately 3% strain, the primary cracks in the Inconel overcoat act as stress concentrators and generate through thickness cracks in the Ag film (secondary cracks). The primary Inconel cracks had a saturation spacing of 1.5  $\mu\text{m}$ , while the secondary Inconel-Ag saturation crack spacing was much larger at 12  $\mu\text{m}$ . In-situ fragmentation experiments performed through the transparent Teflon substrate revealed only the secondary through thickness cracks and cross-sectional focused ion beam characterization provides further evidence for the two-stage cracking behavior. Using the shear lag model the interfacial shear stresses of the Inconel and Inconel-Ag layers were determined from the saturation crack spacings and observed fracture strains. These results further illustrate that brittle layers at any position are detrimental to the functionality of multi-layered metal-polymer systems and should be carefully considered for any application.

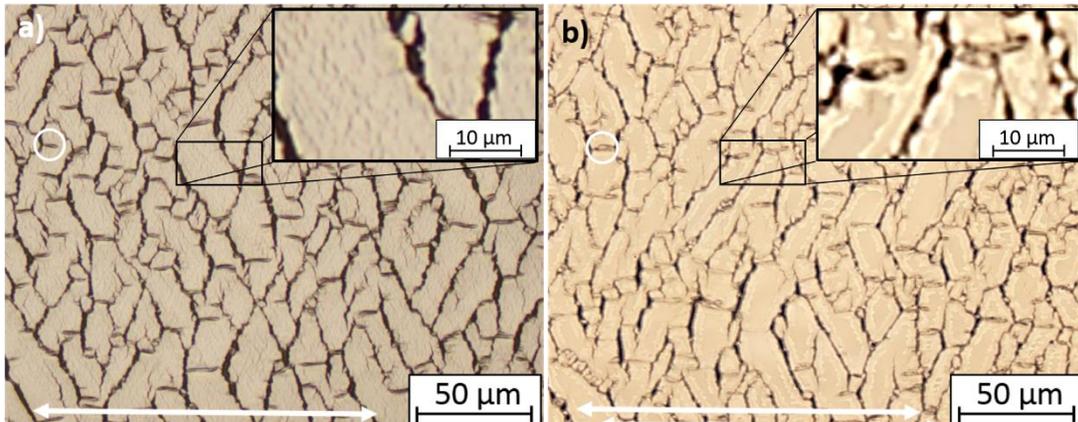


Figure 1 – In-situ optical fragmentation analysis at  $\epsilon=15\%$  revealing a two-stage fragmentation process. a) Top view of the Inconel overcoat. Small primary cracks in the Inconel layer (inset) and through thickness cracking (TTC) through both layers are visible. b) Bottom view of Ag layer through the transparent FEP substrate showing only TTC. Buckling parallel to straining direction (indicated with white circles) is visible on both sides indicating that delamination occurs at the Ag-FEP interface.