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MECHANICAL RESPONSE OF ALUMINUM/POLYIMIDE STRETCHABLE UNITS: A COHESIVE ZONE MODEL APPROACH

R. Lucchini[1], E. Cattarinuzzi[2], D. Gastaldi[3] and P. Vena[4]

[1] CMIC, LaBS, Politecnico di Milano, Milano, Italy, riccardo.lucchini@polimi.it
[2] CMIC, LaBS, Politecnico di Milano, Milano, Italy, emanuele.catterinuzzi@polimi.it
[3] CMIC, LaBS, Politecnico di Milano, Milano, Italy, dario.gastaldi@polimi.it
[4] CMIC, LaBS, Politecnico di Milano, Milano, Italy, pasquale.vena@polimi.it

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INTRODUCTION

Stretchable electronics refers to large area devices in which compliant polymeric substrates support micron-size sensor units. Electrical continuity between these nodal points enables distributed measurements over complex surfaces, opening new perspectives in many application fields. Since the micro-electronic units are small stiff islands, electrical conductivity and stretchability mostly rely on suitably designed compliant interconnects, which should be able to confer mechanical reliability within the whole range of expected deformation. Stretching-induced delamination, with the development of cohesive and adhesive fracture, is one of the major factors limiting the capability to achieve large deformation for a given interconnect. In this work an ad hoc cohesive formulation has been developed and integrated into a suitable finite element model focusing on the interface delamination upon stretching of compliant interconnects made of aluminum (Al) on polyimide (PI).

FINITE ELEMENT MODEL AND COHESIVE ZONE MODEL FORMULATION

Finite element models within the commercial code ABAQUS 6.12 (Simulia, Dassault Systemes, France) have been developed, based on experimental results of tensile tests carried out on stretchable interconnects of different geometries. The submodeling technique is applied with the purpose to gain detailed information on small size area around the metal/polymer interface and to achieve a sufficient mesh refinement with reduced computational effort. A global model, able to represent the sample behavior exploiting periodic boundary conditions, is used to determine displacement-based boundary conditions to local, and more refined, models focusing on the interface. The local model is also enriched using cohesive elements with a suitably implemented interface constitutive law able to account for interface degradation.
The traction vector T acting at the cohesive surface modeling the interface between the metal and polymer layers is derived from the interfacial potential proposed by Xu and Needleman[1]. The original formulation by Xu and Needleman will be suitably modified in order to account for three-dimensional problems; furthermore, additional modifications will be introduced with the purpose to model a loading-unloading asymmetric response and to couple the different directions in order to account for mixed-mode delamination. Normal and shear traction components are presented as functions of the normal and tangential opening displacements Δn and $\Delta\tau$ in figure 1 A and 1 B, respectively.

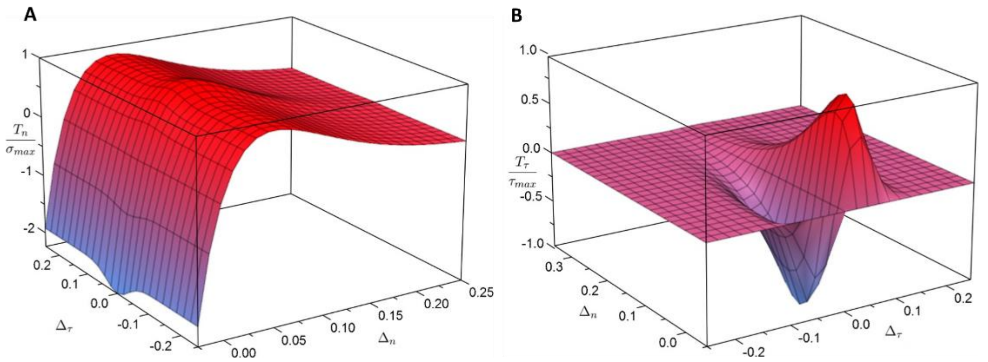

Fig.1 Normal (A) and shear traction (B) cohesive surface normalized respect the maximum normal and shear stress. Considering the isotropy in the shear direction, only one tangential traction component is presented for the shear behavior.

RESULTS

Realistic simulation of the deformed shape of stretchable interconnects affected by delamination was achieved by means of the proposed FE model, an example is represented in figure 2.

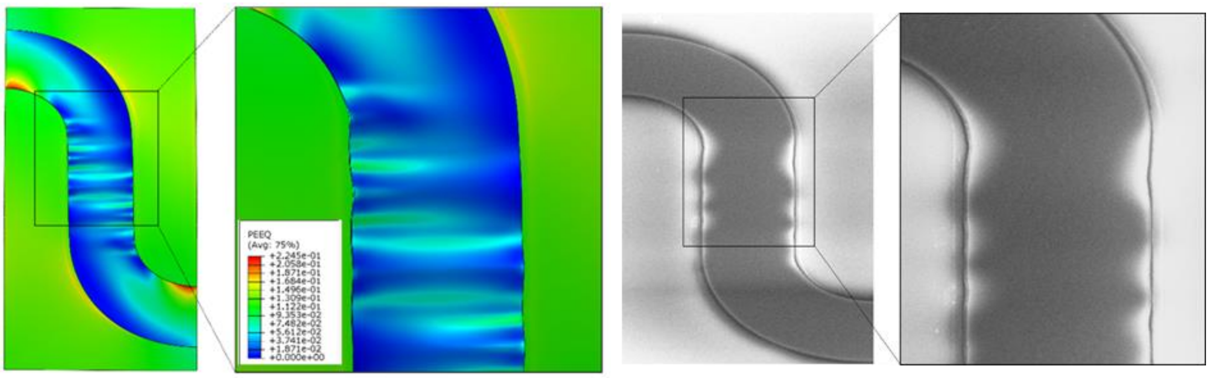

Fig. 2: Comparison between numerical results and ESEM images acquired during an IN-SITU micro tensile test. (on the left) Spatial distribution of the accumulated plastic strain on a portion of the local model, (on the right) ESEM images at 400X and 2000X magnification.

The submodeling approach allowed to reduce computational costs when modeling the mechanical response at the macroscopic level, meanwhile ensuring sufficient mesh refinement at the local level, to properly model the process zone length and describe the propagation phenomena. The cohesive mixed-mode formulation yielded delamination morphologies consistent with experimental observations, thus assessing the relevance of irreversible and coupled normal-tangential behavior.

REFERENCES

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