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Cohesive Modelling for Spontaneous Adhesion in Microelectromechanical Systems

Raffaele Ardito[1], Alberto Corigliano[1], Biagio De Masi[1] and Attilio Frangi[1]

[1] Department. of Structural Engineering
Politecnico di Milano
Piazza Leonardo da Vinci 32, Milano, Italy
corresponding e-mail: alberto.corigliano@polimi.it

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ABSTRACT

The reliability of microelectromechanical systems (MEMS), namely microengines and miniaturized sensors, is often limited by phenomena of spontaneous adhesion between parts which should maintain the capability of relative motion. The issues of catastrophic adhesion, but also of dangerous increments of friction, are often referred to in the literature with the term “stiction”, contraction of “static friction”. Many research efforts are currently devoted to stiction phenomena, both from the experimental point of view and in the ambit of predictive simulations, and to the study of possible provisions apt to reduce their effects on MEMS operation (see the review papers [1] and [2]).

The main source of adhesion, in the presence of humidity, is represented by the capillary tension in water droplets condensed around the asperities of the contacting surfaces. In dry conditions, the uncharged surfaces stick to each other because of different forces, among which the most important ones are represented by the short-range intermolecular Van der Waals interactions [3].

This communication aims at the formulation of a computational model capable to simulate the adhesion in various situations. The model is based on the concepts of fracture mechanics, which are often used to relate the interface adhesion energy to the geometric configuration of the system, see e.g. [4]. Hence, when considering the finite element model, the adhesive behaviour is simulated by introducing some cohesive interface elements on the contacting surfaces. The fracture energy connected to the chosen interface model must equal the surface energy, which in turn can be experimentally measured in different environmental conditions.

The cohesive law must be able to interpret the basic features of adhesion, which is basically controlled by what happens at the microscale. For this reason, a sort of multiscale procedure has been devised, in the sense that the macroscale interface model is tuned on the basis of detailed computations carried out at the microscale, on a representative part of the surface. In this way, it is possible to catch some essential aspects of stiction, most of which are related to the microscopic roughness.

The geometric model of the rough surface can be either artificially generated on the

basis of a priori known statistical properties [3] or reconstructed after some direct experimental measurements, for instance by means of the Atomic Force Microscope (AFM) [5]. The microscale analyses include the contact behaviour of the asperities and the mechanical deformation of the bulk material, which is comparatively modelled as elastic-plastic or rigid-plastic. The effect of capillary tension is evaluated, by considering that the amount of capillary condensation is strongly dependent on the degree of relative humidity and on the roughness geometry. Finally, Van der Waals forces are estimated by properly introducing a molecular interaction potential [6]. The microscopic analyses are carried out many times, changing some significant environmental parameters, namely the relative humidity and the temperature.

The results achieved at the microscale are exploited in the definition of the macroscopic interface model, whose validity is assessed by considering some simple experimental results reported in [7]. The experimental setup is represented by microscopic beams which are electrostatically actuated in order to adhere to the substrate (pull-in). After the adhesion, the imposed voltage is decreased until the structure is fully detached (pull-out). During this process, the average displacement of the system is measured by an interferometric procedure. The difference between pull-out and pull-in voltage can be correlated to the adhesion energy, which can be numerically computed by means of the aforementioned model. Further comparisons are carried out by critically examining other results reported in the literature.

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