ADHESION OF ELASTIC PUNCH TO CONFINED ELASTIC LAYER

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1. Introduction

In nature, several different strategies can be found for temporary and reversible adhesion to various substrates. Animals usually employ various hairy contact structures to ensure the necessary adhesive mechanisms. Among hundreds of animal species, gecko is considered to be one of the most interesting ones in terms of the body weight and its excellent ability to climb on vertical surfaces. Experimental measurements revealed that adhesion ability of gecko is explained by the van der Waals interaction between the contacting substrate and the hairy feet of gecko. Adopting nature's perfect adhesion solution in artificial structures is a primary goal of engineers and scientists in this research field. It is undoubtedly evident that the proper utilization of nature's adhesion mechanism in technological applications could lead to significant improvements in various fields of engineering devices.

Confined elastic layers are widely used in adhesive technologies, including micropatterned adhesives as well [1-4]. In order to properly understand the adhesive behavior of these structures, it is essential to investigate the stress distributions along the contacting interfaces. Furthermore, the classical linear elastic fracture mechanics approach can be used to analyze the variation of the energy release rate if local defect or detachment appears along the interface. Characterization of the stress distributions and the fracture mechanics related behaviors help us in improving the performance of these artificial structures.

The normal stress distribution along the interface of a rigid cylindrical punch and a confined elastic layer was recently characterized in detail for different values of the Poisson's ratio [5]. The variation of the energy release rate for the detachment process was also analyzed and the critical thickness of the layer was found to have stable detachment mechanism [5].

The complete characterization, including the analysis on the variation of the energy rate upon detachment, for the adhesion of an elastic punch to confined elastic layer is not available in the literature. However, its importance in technical applications is evident.

2. Problem description

The investigated axisymmetric problem is depicted in Fig. 1. A linear elastic cylindrical punch is attached to a linear elastic layer, which is considered to be infinite in radial direction. The punch height is L, whereas its radius is denoted by a. The layer thickness is h. The Young's moduli for the punch and the layer are E_1 and E_2 ,respectively. Here, only incompressible case is investigated, thus, the Poisson's ratio is set to 0.5 for both materials.

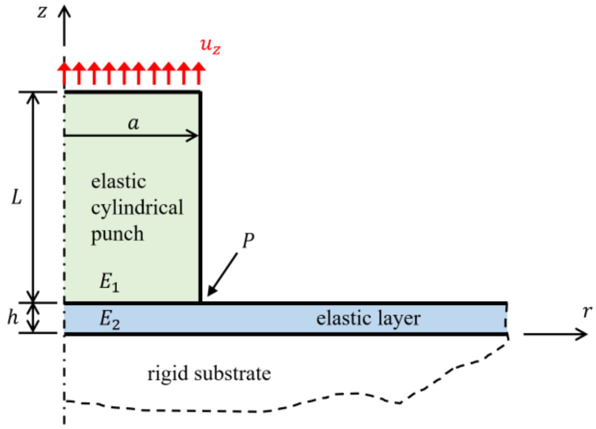

Fig. 1. Geometry of the investigated axisymmetric problem.

The bottom of the layer is perfectly attached to the rigid substrate, no sliding allowed. Perfect bonding is assumed along the interface between the punch and the layer. The loading of the structure is given by the prescribed vertical displacement applied along the top surface of the punch, whereas the radial displacement is not constrained.

It is obvious that stress singularity appears along the perimeter P of the interface in both materials.

The primary goals in the analysis: a) characterization of the stress distribution along the interface b) calculating the energy release rate and its derivative if small radial defect is forming along perimeter P. It must be emphasized that analytical solution for the problem does not exist.

3. Results

The problem is solved using the commercial finite element software ABAQUS version 2019. Eight-noded quadratic axisymmetric hybrid elements were used with full integration scheme. The mesh was extensively refined in the singularity domains.

The derivative of the energy release rate with respect to the defect area along P can be used to check the stability of the detachment. Quantity $\bar{G}'$ measures the normalized dimensionless value of the derivative of the energy release rate with respect to the contact area. If G decreases with the increasing defect area then $\bar{G}'$ is positive, which predicts stable detachment process. The values of $\bar{G}'$ for different layer thickness and for different values of the ratio E_1/E_2 is shown in Fig. 2. One can conclude that the stable domain is a function of the layer thickness and the ratio of the moduli.

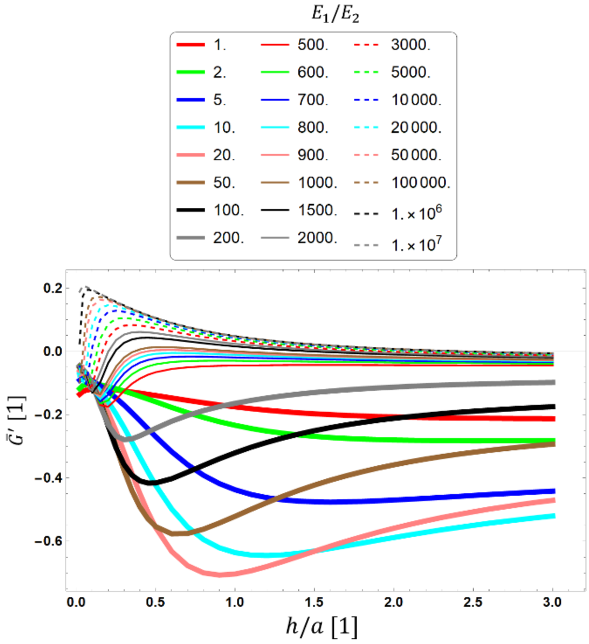

Fig. 2. Variation of the derivative of the normalized energy release rate.

Fig. 3. shows the stability map in the plane of the layer thickness and the ratio of the moduli.

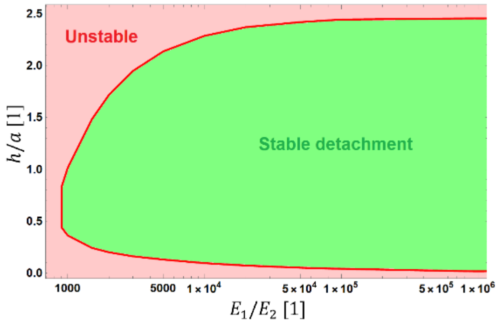

Fig. 3. Illustration of the stable and unstable domains.

The results clearly revealed that the detachment initiation process is unstable for arbitrary layer thickness as long as the ratio E_1/E_2 does not reach a critical value. Higher the value of the ratio of the Young's moduli, larger the stable domain for the layer thickness. Furthermore, the detachment for very thin layers is always unstable if the punch is elastic. The limit case is when the punch is rigid. Then, the process is stable for thin layers as discussed in [5]. For very thick layer the detachment is always unstable for elastic and rigid punches as well.

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