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INVESTIGATIONS OF COHESIVE ZONE PROPERTIES OF THE INTERFACE BETWEEN METAL FILM AND CERAMIC SUBSTRATE AT NANO- AND MICRO-SCALES

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ABSTRACT

Cohesive zone characterizations of the interface between metal film and ceramic substrate at micro- and nano-scales are performed in the present research. At the nano-scale, a special potential for special material interface (Ag/MgO) is adopted to investigate the interface separation mechanism by using MD simulation, and stress-separation relationship will be obtained. At the micro-scale, peeling experiment is performed for the Al film/Al_2O_3 substrate system with an adhesive layer at the interface. Adhesive is a mixture of epoxy and polyimide with mass ratio 1:1, by which a brittle cohesive property is obtained. The relationships between energy release rate, the film thickness and the adhesive layer thickness are measured during the steady-state peeling. The experimental result has a similar trend as modeling result for a weak adhesion interface case.

Key Words: cohesive zone, energy release rate, interface energy, peel test

INTRODUCTION

Due to extensive applications of the thin film/substrate systems in engineering, the researches on the strength, ductility and reliability of the systems have attracted great deal of interest in recent years [1–3]. It is well known that the above properties are mainly dependent on the interface adhesion property, which is often described by the cohesive zone (CZ) property. The CZ property is equivalent to a two- parameter criterion. Two parameters are the interface energy and the interface separation strength. Therefore, in order to deeply explore interface property, it is very important to investigate the microscopic mechanism of the cohesive zone and to develop a trans-scale theory for the CZ model. In the present research, interface separation mechanism at nanoscale is studied by using MD simulation, and interface property at microscale is measured by using the peel test experiments.

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PEELING EXPERIMENTS OF ENERGY RELEASE RATE

As mentioned above, there are two important parameters in the CZ model, ($\Gamma_0, \hat{\sigma}$), where Γ_0 is the interfacial fracture energy and $\hat{\sigma}$ the adhesion strength. The determination of ($\Gamma_0, \hat{\sigma}$) for a film/substrate system is the most important goal. Through the peel test measurements, see Fig. 1(a), one can record both the energy release rate (or peel force P) and the deformation information of the film. From energy balance at the steady-state peeling, one can obtain a relationship between energy release rate $P(1-\cos\Phi)$ with interfacial fracture energy Γ_0 as well as plastic dissipation energy Γ_P of the film,

$$P(1-\cos\Phi) = \Gamma_0 + \Gamma_P \qquad (1)$$

In most metal film cases Γ_P is a major contribution to the energy release rate $P(1-\cos\Phi)$. So an appropriate method is needed to determine Γ_0 [4-6].

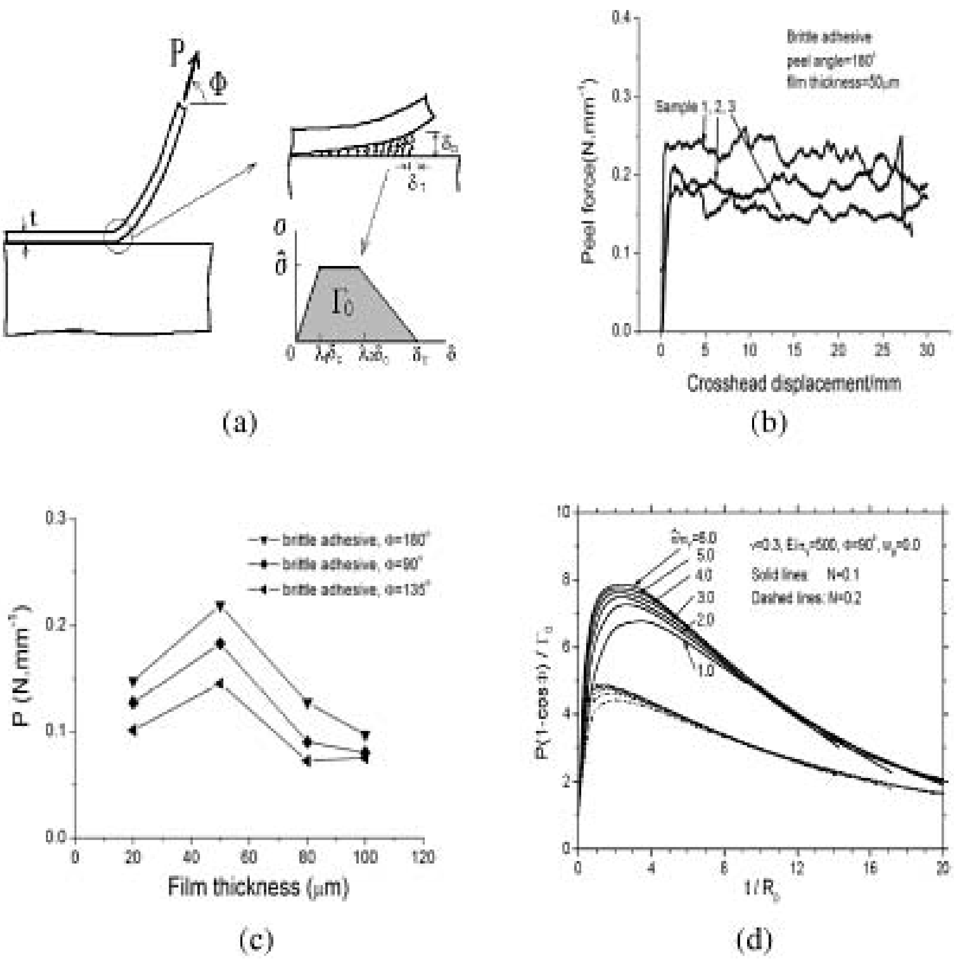

Figure 1. (a) Sketch figure of peel test and cohesive zone model. (b) Peel force (or energy release rate) variation, quickly obtaining a steady-state. (c) Variation of the steady-state energy release rate with film thickness. (d) Bending model results of the steady-state energy release rate. Clearly, both modeling and experimental results have similar trend.

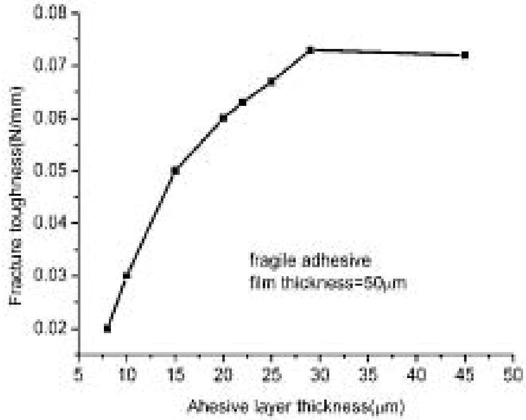

Figure 2. Variation of interface fracture energy with the adhesive layer thickness.

Peeling experiment is performed for the Al film/Al_2O_3 substrate system with an adhesive layer at the interface. Adhesive is a mixture of epoxy and polyimide with mass ratio 1:1, by which a brittle cohesive property is obtained. The relationships between energy release rate, the film thickness and the adhesive layer thickness are measured during the steady-state peeling, as shown in Fig.1(b) and (c). From Fig. 1(b), variation of peel force with loading displacement displays that it is very easily to get at the steady-state peeling process, i.e., a stable peel force state. For a series of film thicknesses, Fig.1(c) shows the variations of the steady-state peel forces (energy release rate) with thin film thickness.

MODELING OF PEEL TEST BASED ON CZ AND BENDING MODELS

There are several analytical models which can be used to model the peel test[6]. The most popularly used model is the CZ model based on the beam bending theory. However, this model is suitable for a weak interface adhesion case, as present discussed brittle adhesive case [7]. Using this model, we find out the analytical solution for the peel test, as shown in Fig. 1(d). Clearly, both analytical and experimental results have the similar trend.

It is also an important goal for the peel test to determine the interface mechanics parameters. We used the neural network method and the experimental measurement of the steady-state energy release rate to develop a approach to determine the interface fracture energy and separation strength. The variation of the interface fracture energy with the adhesive layer thickness is shown in Fig.2.

FUNDAMENTAL INVESTIGATIONS ON THE CZ PROPERTIES

It is very significant to explore the CZ property at the atomistic scale. We consider an interface of Ag/MgO, and use a specially developed potential for the interface [8] to obtain the interface cohesive zone relation, as shown in Fig.3. This result is similar with that obtained by Smith et al.[9] for the interface of Ni/Al_2O_3.

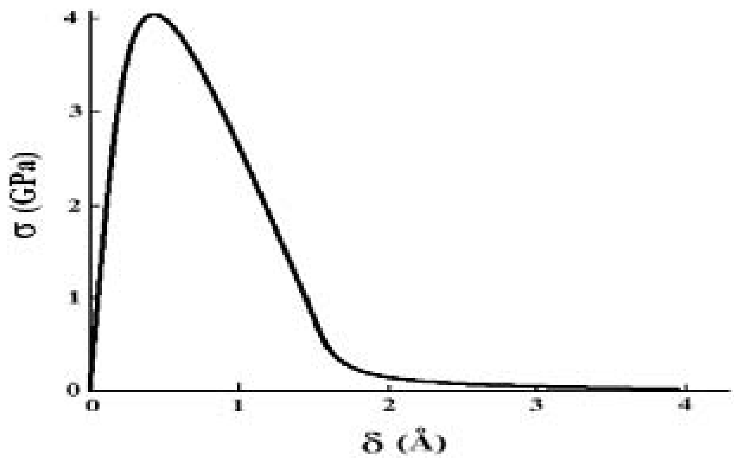

Figure 3. CZ property for the interface of Ag/MgO by using the MD simulation.

CONCLUDING REMARKS

In the present research, fundament and application of the CZ model have been investigated. It is worth of noting that a trans-scale theory is needed to link the microscopic CZ model and macroscopic CZ model in further research.

REFERENCES

1. Cotterell, B., Hbaieb, K., Williams, J.G., Hadavinia, H., Tropsa, V. 2006. "The root rotation in double cantilever beam and peel tests". *Mechanics of Materials* 38: 571–584.
2. Hadavinia, H., Kawashita, L., Kinloch, A.J., Moore, D.R., Williams, J.G. 2006. "A numerical analysis of the elastic-plastic peel test". *Engineering Fracture Mechanics* 73: 2324–2335.
3. Pardoen, T., Ferracin, T., Landis, C.M., Delannay, F. 2005. "Constraints effects in adhesive joint fracture". *Journal of the Mechanics and Physics of Solids* 53: 1951–1983.
4. Wei, Y., Hutchinson, J.W. 1998. Interface strength, work of adhesion and plasticity in the peel test. *International Journal of Fracture* 93: 315–333.
5. Wei, Y. 2002. "Thin layer splitting along the elastic-plastic solid surface". *International Journal of Fracture* 113: 233–252.
6. Wei, Y. 2004. "Modeling nonlinear peeling of ductile thin films—critical assessment of analytical bending models using FE simulations". *International Journal of Solids and Structures* 41, 5087–5104.
7. Wei, Y., Zhao, H. 2008. "Peeling experiments of ductile thin films along ceramic substrates—critical assessment of analytical models". *International Journal of Solids and Structures* (In Press).
8. Long, Y., Chen, N.X., Zhang,W.Q. 2005. "Pair potentials for a metal-ceramic interface by inversion of adhesive energy". *Journal of Physics-Condensed Matter*, 17: 2045–2058.
9. Smith, J.R., Jiang, Y., Evans, A.G. 2007. "Adhesion of the gamma-Ni(Al)/alpha-Al2O3 interface: a first-principles assessment". 98: 1214–1221.