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The effect of crack nucleation and growth on the mechanical properties in nanoindentation test

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Introduction

Nanoindentation testing, also referred to as instrumented indentation testing, is widely used for the mechanical characterization of small volumes of materials. Since the application of coatings in industry has lately increased, accurate determination of the mechanical properties of coatings became one of the most important concerns for scientists. Complete understanding of the mechanisms of crack initiation and growth seems necessary to determine the sources of error during nanoindentation test.

There are few publications in the literature on the mechanisms of interfacial crack growth in the presence of pre-existing defect (Chen,J., Bull, S.J., 2009). Existence of pre-existing defect along the interface between the coating and the substrate leads to sooner initiation of the interfacial crack (Chen,J., Bull, S.J., 2009). One of the important issues that were not mentioned in previous works is the position of the pre-existing defect and its effect on the failure mechanisms and mechanical properties.

In this study we consider elastic-plastic coating on elastic-plastic substrate system and the cohesive zone model embedded in the finite element code is used to simulate the interface between coating and its substrate. The aim of this paper is to investigate the effect of interfacial crack growth in the presence of a defect on deformation behavior and some mechanical properties such as hardness and modulus of elasticity in Cu/Si coating system. The reason that we choose Cu/Si interface is that experimental results show that the interface between Cu and Si layers in Si/Cu/SiN/Pt/C multilayer coating stuck is the most probable interface to delaminate during the test (Zhao, P. et al, 2010).

Model description

In this study, the simulated sample consists of cu layer lying on a silicon substrate. The diameter and the thickness of coating are 5 and 0.2 micrometer, respectively. A 0.5 micrometer height sharp Berkovich indenter was simplified as a 70.3°equivalent cone. Material properties are listed in Table 1. Table 2 lists the test structures examined in this study.

Table 1 Material properties of components

Component	E (GPa)	σ_y (GPa)	ν	m
Cu	110	0.052	0.343	0.54
Si	168	7	0.28	0

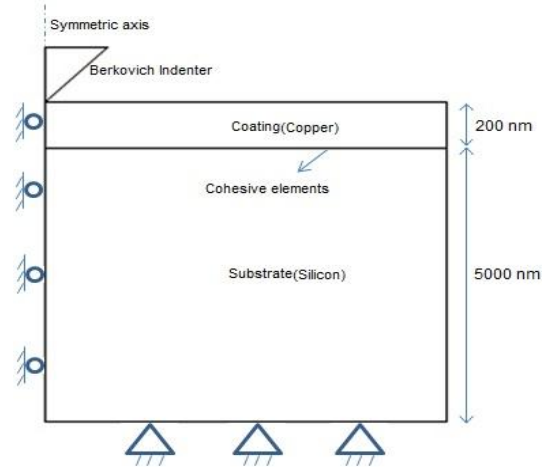


Fig. 1 Model geometry.

Table 2 Test structures

	σ_{max} (MPa)	δ_n (μ m)	δ_i (μ m)	Defect's position (μ m)	Defect's length (μ m)
Case1	280	0.004	0.004	-	-
Case2	280	0.004	0.004	0.66	0.15
Case3	280	0.004	0.004	0.35	0.15
Case4	280	0.004	0.004	0.14	0.15

Results and Discussion

Fig. 2 depicts the load–displacement curves for 3 cases with various positions of initial defect at a maximum penetration of 200 nm. Before initiation of the crack, there is not any difference between curves. As the crack initiates, the reaction load falls slightly. Growing the crack leads to dramatic decrease in the amount of reaction load. Sooner reduce is observed by the presence of pre-existing defect.

This chart reveals that the position of a defect has significant effect on the load-indentation depth curve and not considering the presence of a defect may lead to noticeable error in calculation of some mechanical properties.

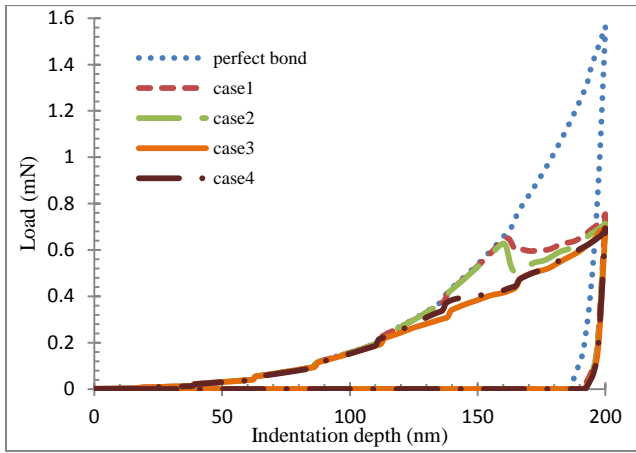


Fig. 2 Load-indentation depth diagram.

Fig. 3 shows the variation of crack length versus indentation depth during loading. Whatever the pre-existing defect is nearer to the shear stress concentration point, then crack will initiate sooner. When no defect exists, crack initiates later but the slope of its growth is further.

This chart demonstrates that the location of pre-existing defect plays an important role in the initiation and speed of growing the crack.

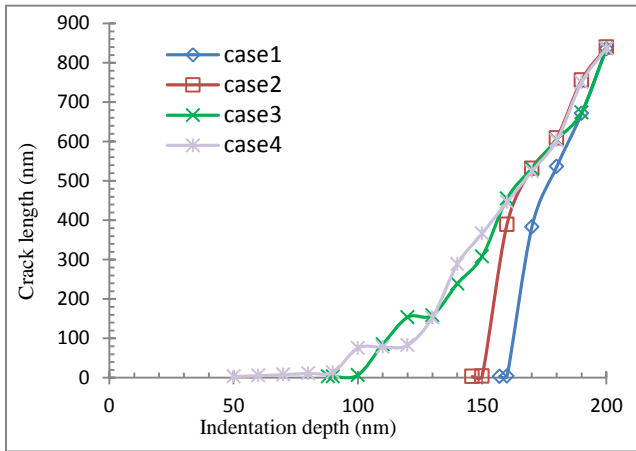


Fig. 3 The variation of crack's length versus indentation depth during loading.

Hardness and modulus of elasticity were evaluated by the method of Oliver and Pharr [Oliver, W.C., Pharr, G.M., 1992], to investigate what happens to it when the crack initiates and grows. Fig.4 shows the variation of hardness with indentation depth. Fig.5 displays the variation of reduced modulus of elasticity with indentation depth. The values of hardness at different depths of indentation are directly related to the maximum load at the maximum indentation depth and initiation the crack leads to significant reduce in reaction load so the hardness is dropped when crack initiates. As the pre-existing defect is nearer to the shear stress concentration point, then hardness will decline sooner.

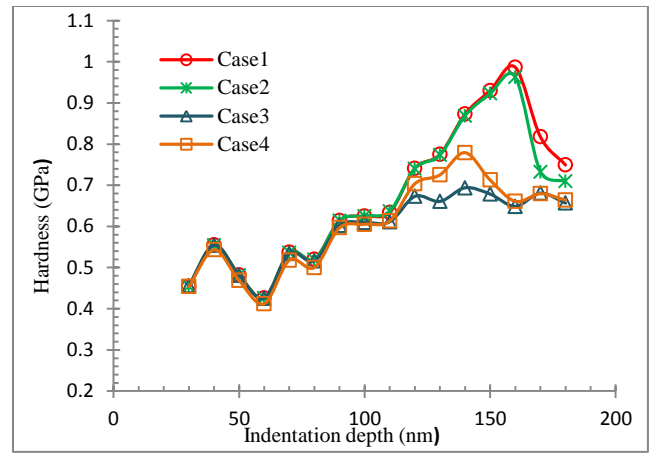
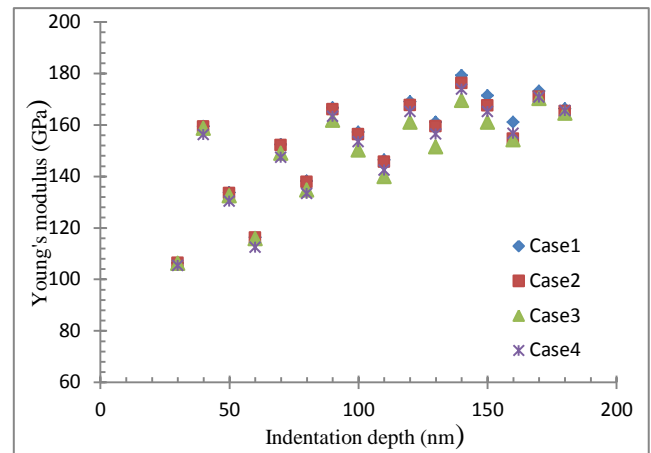


Fig. 4 The variation of hardness with indentation depth.

Fig. 5 The variation of reduced modulus of elasticity with



indentation depth.

Conclusion

The main conclusions are listed below:

- The position of a defect has significant effect on the load-indentation depth curve and not considering the presence of a defect may lead to noticeable error in calculation of some mechanical properties.
- Interfacial crack growth totally regarded on the position that pre-existing defect is defined. Whatever the position of the defect is nearer to the point that shear stress concentration exist, then the crack will initiate sooner.
- Crack growth results in some error in calculation of the amount of hardness and according to the range in which the interfacial crack has grown, the amount of error is different.

References

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