ANALYSIS OF FRACTURE BEHAVIOUR OF MULTILAYERS BY CANTILEVER AND CLAMPED BEAM BENDING GEOMETRY

Ashwini Kumar Mishra[1]*, Hariprasad Gopalan[2], Marcus Hans[3], Tejas Chaudhari[1]
Christoph Kirchlechner[2], Jochen M. Schneider[3], Gerhard Dehm[4], Balila Nagamani Jaya[1]

[1]Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, India, [2]Institute of Applied Materials, Karlsruhe Institute of Technology, Germany, [3]Materials Chemistry, RWTH Aachen University, Aachen, Germany, [4]Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany
** Presenting Author email: ashwini.mishra013@gmail.com*

Abstract
Multilayering of metal/ceramic combinations can help to achieve better strength and toughness than the individual material constituents. The effect of elastic-plastic mismatch in multilayers on the crack driving force and eventually on fracture resistance has been analyzed in this work. The enhancement in fracture toughness by decreasing layer spacing has been predicted from finite element calculations and verified by micro-cantilever fracture tests. Further, calculations have been carried out for a more stable clamped beam bend geometry to determine R-curve behavior in such multilayers.

1. Introduction
High strength and high fracture toughness can be achieved in multilayer metal/ceramic composites. Sputtered Ti/TiN multilayer thin films have been shown to display increased crack resistance with decreasing layer spacing. This enhancement in fracture toughness is due to variation in crack tip driving force in multilayers. When the crack tip lies in the soft material facing the hard material in front of it, it experiences a shielding effect. The opposite leads to an anti-shielding effect. The amplitude of these oscillations in crack driving force is computed using finite element modeling. All cantilevers display catastrophic failure, due to the instability of the geometry. Hence further experiments are suggested using the more stable clamped beam bend geometry.

2. Results
The elastic properties of single layer Ti, TiN, 3 layer Ti/TiN, 10 layer Ti/TiN, and 50 layer Ti/TiN have been determined using nanoindentation. Plastic properties of Ti are determined by unnotched micro-cantilever bending and inverse modeling. These have been used as inputs for finite element modeling of crack tip driving force. With increasing the number of interfaces (or decreasing layer spacing), multiple shielding and anti-shieling effects operate (Fig 1a), resulting in an overall enhancement in fracture toughness (Fig. 1b). Fracture toughness determined from micro-cantilever bending shows that the 50 layer Ti/TiN has 82% higher fracture toughness than TiN (as shown in Fig. 1b), while maintaining a similar hardness. Catastrophic failure has been observed in all multilayer samples, hence, a stable geometry is required. It is seen that elastic mismatch plays the predominant role in the shielding of the crack tip.

Calculations done using the clamped beam geometry consider elastic mismatch only. In this geometry, even in the case of the anti-shielding effect, the crack tip driving force decreases after a certain stability point. The cantilever beam and clamped beam have been compared for the same 3 layer Ti/TiN system which shows better crack stability in clamped beam geometry (Fig. 1c). In the 3 layer Ti/TiN/Ti, the thickness of the 1st layer (Ti) was kept constant and the thickness of the 2nd layer TiN is varied. The maximum shielding effect is shown in the case where the thickness of the 2nd layer TiN is highest, as expected. Using this analysis, further 10 layer Ti/TiN systems are analyzed in which the thickness of the TiN is systematically varied. It has been found that the 10 layer systems with a maximum thickness of the stiffer layer will give the least driving force. This implies that a multilayer design that has a high ratio of ceramic (stiff, hard) to metal (compliant, soft) thickness can achieve both higher fracture toughness and higher hardness.

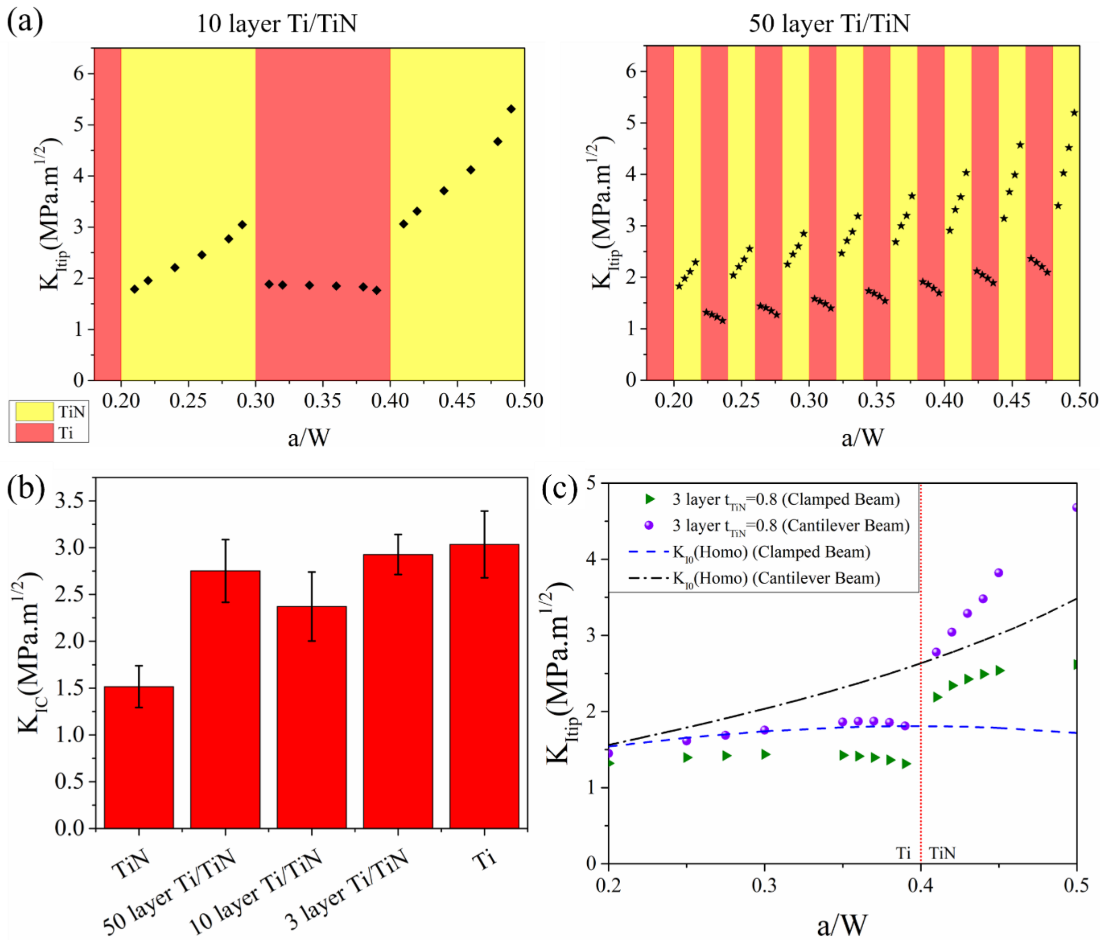

Fig.1 – Crack tip driving force for 10 layer and 50 layer Ti/TiN b) fracture toughness of thin film tested by micro-cantilever bending c) comparison of crack tip driving force for cantilever and clamped beam geometry for 3 layer Ti/TiN (reproduced with permission from [1])

3. Conclusions

Numerical modeling predicts higher fracture toughness for multilayer systems with a larger number of interfaces. Finer spacing experiences a lower ratio of a crack driving force to fracture toughness in each layer, thereby leading to a higher initiation fracture toughness, which is validated by micro-cantilever testing. Further crack tip driving force solutions for an elastically mismatched multilayer clamped beam has been developed. TiN sandwiched between thin Ti layers leads to shielding and can help inhibit crack propagation in the brittle TiN. Increasing the number of layers and increasing the thickness of stiffer layers is effective in applications that require both high strength and high fracture toughness. The clamped beam is shown to be better than the cantilever beam for R-curve measurements of multilayers.

Acknowledgments

The authors would like to thank Max Planck Partner Group Project 17MAX001 for financial support.

References

[1] A.K. Mishra, H. Gopalan, M. Hans, C. Kirchlechner, J.M. Schneider, G. Dehm, B.N. Jaya, Strategies for damage tolerance enhancement in metal/ceramic thin films: Lessons learned from Ti/TiN, Acta Mater. 228 (2022) 117777. https://doi.org/10.1016/j.actamat.2022.117777.