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[1] S. Lotfian, M. Rodríguez, K.E. Yazzie, N. Chawla, J. Llorca, J.M. Molina-Aldareguía, Acta Mater. 61 (2013) 4439–4451. [2] S. Lotfian, C. Mayer, N. Chawla, J. Llorca, a. Misra, J.K. Baldwin, J.M. Molina-Aldareguía, Thin Solid Films (2014). [3] A. Misra, J.P. Hirth, R.G. Hoagland, Acta Mater. 53 (2005) 4817–4824. [4] D.R.P. Singh, N. Chawla, G. Tang, Y.-L. Shen, Acta Mater. 58 (2010) 6628–6636. [5] J.Y. Zhang, J. Li, X.Q. Liang, G. Liu, J. Sun, Sci. Rep. 4 (2014).

Layer Orientation and Size Effects on Micropillar Compression of Al/SiC nanolaminates

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Introduction

1. Metal/ceramic nanolaminates show promise as high strength and toughness materials, when reducing the individual layer thickness to nanometer regime (≤100 nm) [1-3].
2. Micropillar compression tests have been widely employed to study the deformation mechanisms of nanolaminates with force generally perpendicular to individual layers [1,4-5].
3. Nanolaminate strength is subjected to "smaller is stronger" effects, which relates not only to the individual layer thicknesses, but to the micropillar size [5].
4. This work is mainly focused on the deformation mechanism study of a typical metal/ceramic Al/SiC nanolaminates as a function of layer orientation and layer thickness/pillar size, by micropillar compression, with the help of finite element analysis (FEA).

Material and Methods

1. Al/SiC nanolaminates with individual layer thickness varying between 10~100 nm were prepared by magnetron sputtering deposition in Los Alamos National laboratory, and they are mounted on epoxy at 0º, 45º and 90º orientations.
2. Focused ion beam (FIB) milling technology was employed to fabricate 0º, 45º and 90º micropillars, with diameter-to-height dimensions of 1x2, 2x4 and 2x6 (unit, μm).

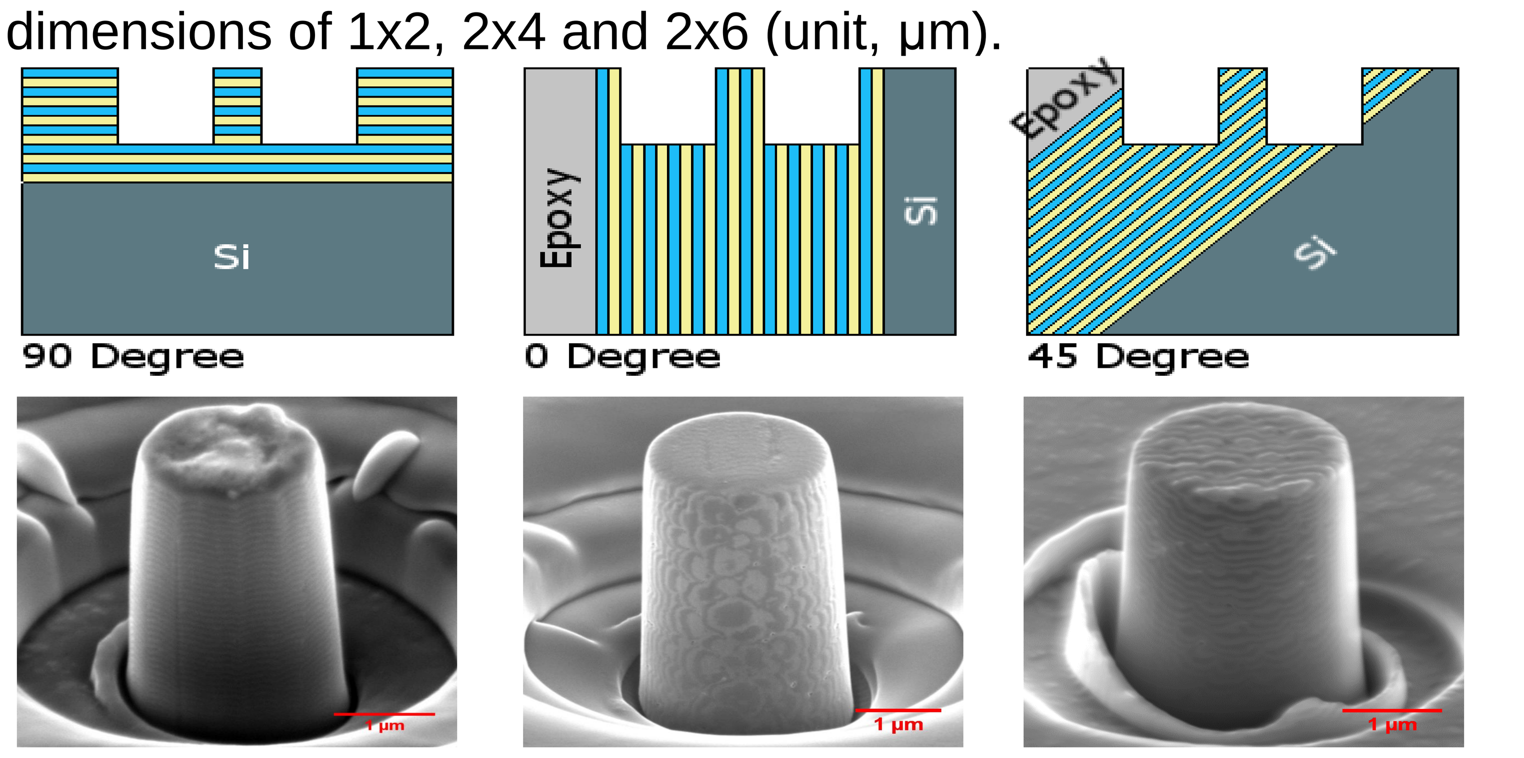

Fig. 1 Schematic of the pillar orientations tested and SEM images of 2x4 μm pillars prior to testing for Al50SiC50

3. FEA was performed to study the micropillar deformation, utilizing commercial Abaqus 6.12. The Al-SiC interface was varied from perfectly flat to adopting sinusoidal waveforms (wave length 0.5 μm, amplitude 0~50 nm) to account for layer waviness effects.

Material	Elastic Modulus	Yield Stress	Poisson's Ratio
Al	70 GPa	935 MPa	0.34
SiC	300 GPa	7 GPa	0.14

Table 1 Material properties of Al and SiC for FEA analysis

Results and Discussion

➢ Effect of Layer Orientation on Al/SiC Deformation

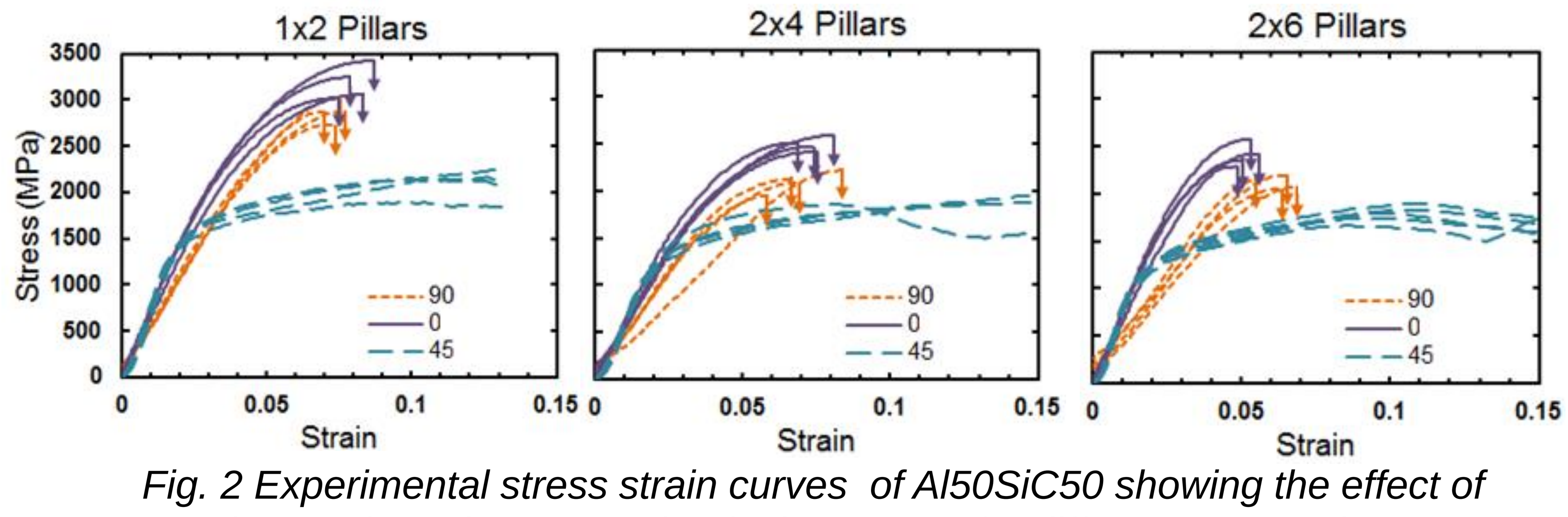

Fig. 2 Experimental stress strain curves of Al50SiC50 showing the effect of layer orientation on mechanical response for different geometries.

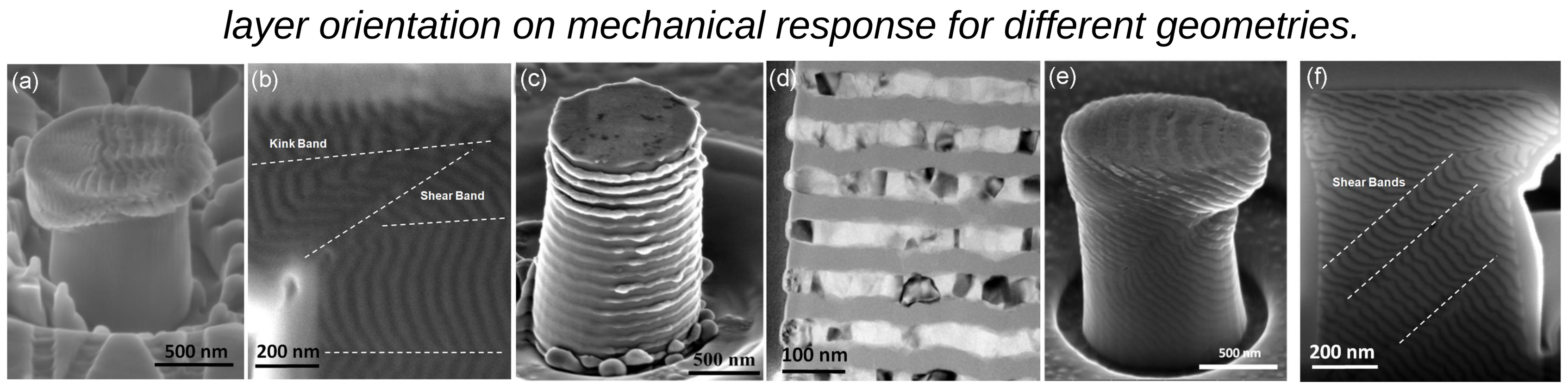

Fig. 3 compressed 1x2 μm micropillars for 0º (a, b), 90º (c, d), and 45º (e, f) orientations.

Al/SiC micropillar strength was highly dependent on layer orientations

➢ Effect of Layer Waviness on Al/SiC Deformation

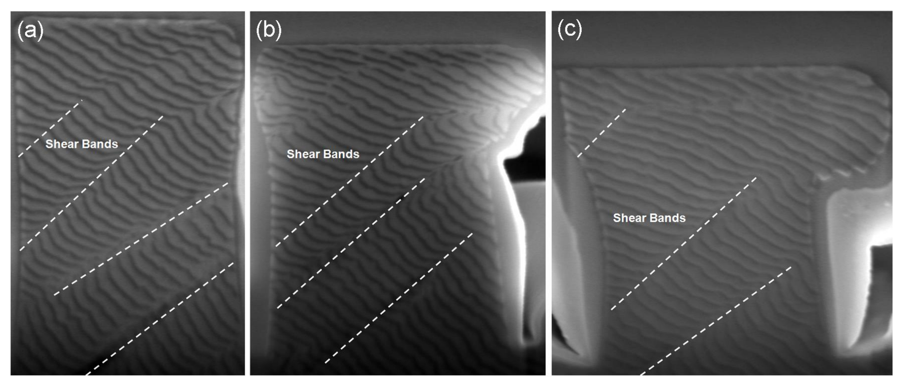

Fig. 4 Cross sectional morphologies of Al50SiC25 with (a) 100 nm, (b) 200 nm, (c) 300 nm compression depth.

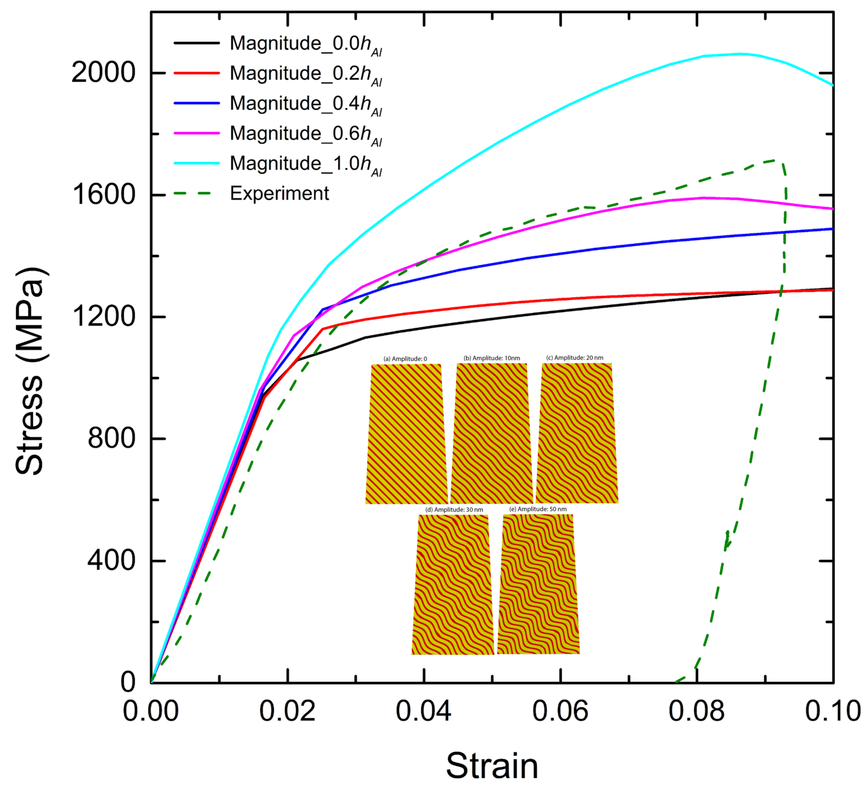

Fig. 5Stress-Strain curves of the experimental and simulated results of Al50SiC25 with varying layer wavines amplitude.

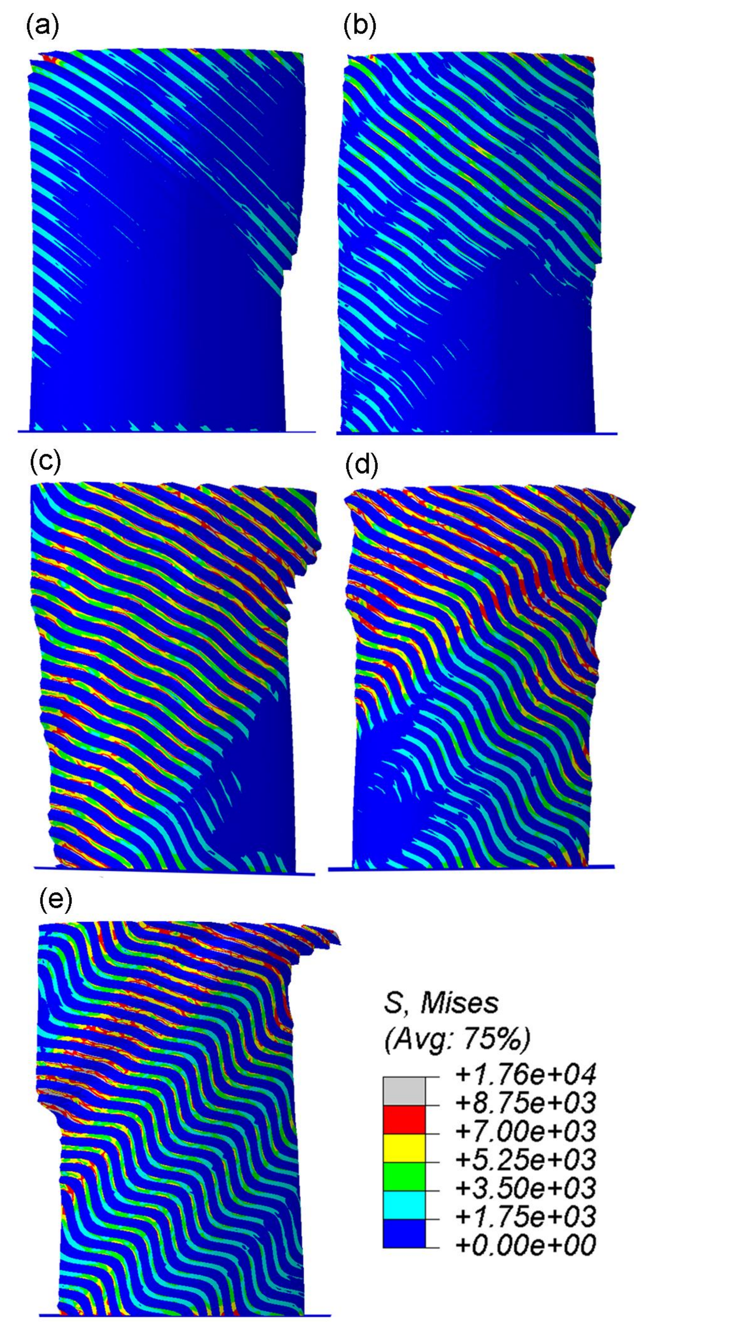

Fig. 6: Mises stress contours of the deformed micropillars with (a) Amplitude: 0; (b) Amplitude: 10 nm; (c) Amplitude: 20 nm; (d) Amplitude: 30 nm; (e) Amplitude: 50 nm.

Layer waviness can have an effect on micropillar strength

➢ Effect of Layer Thickness on Al/SiC Deformation

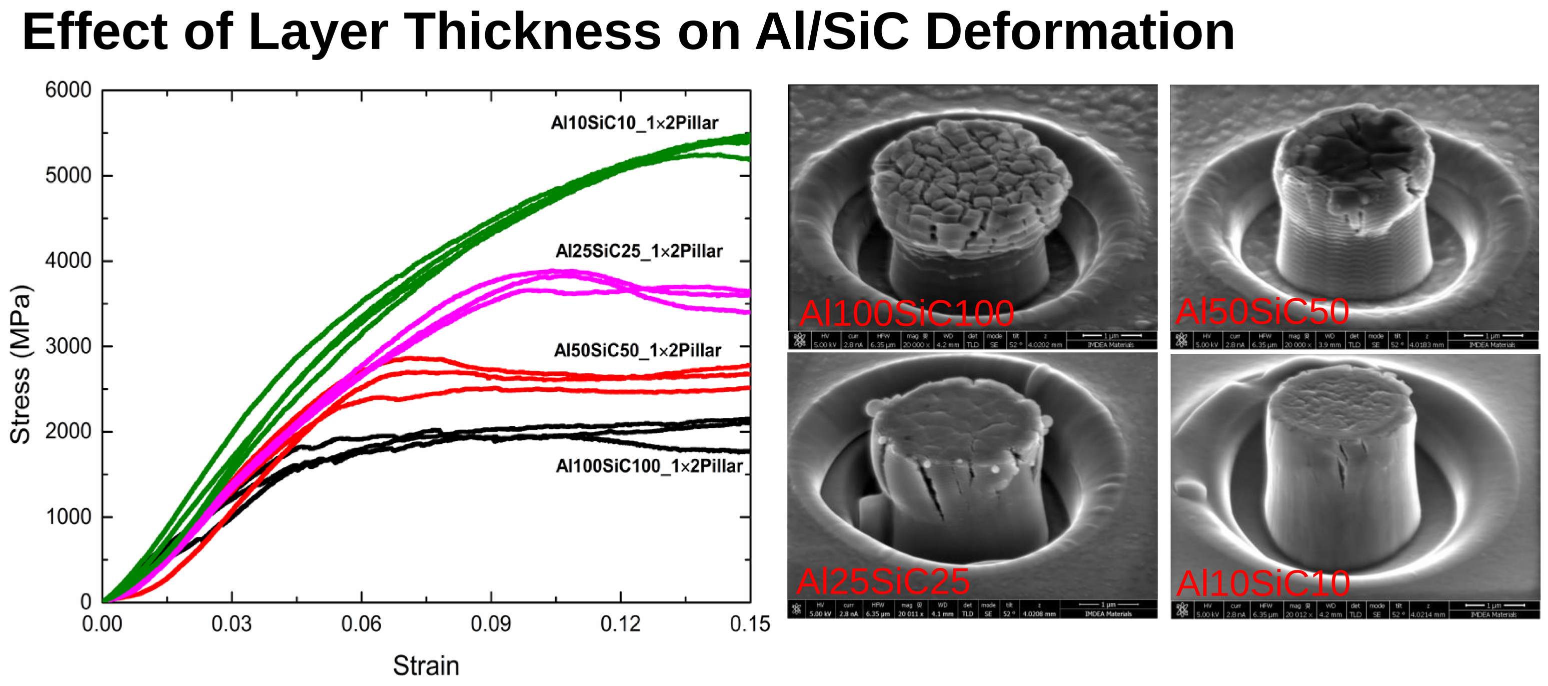

Fig. 7: Engineering stress-strain curves and related deformation morphologies of Al/SiC nanolaminates with varying layer thickness.

A "thinner is stronger" effect was obtained for Al/SiC micropillar strength

➢ Effect of Micropillar Size on Al/SiC Deformation

Weibull distribution function was employed to study pillar size effects:

$$[\ln(\ln\frac{1}{P_S})) - \ln V] = m[\ln\sigma] + [\ln(\frac{1}{V_0}(\frac{1}{\sigma_0})^m)]$$

P_s: Probability of fracture
σ: fracture stress of micropillar
V: micropillar volume
m: Weibull modulus
V_0, σ_0: characteristic volume and strength

The difference in strength with different pillar size can be attributed to the lower probability for the smaller pillars to contain a strength limiting flaw.

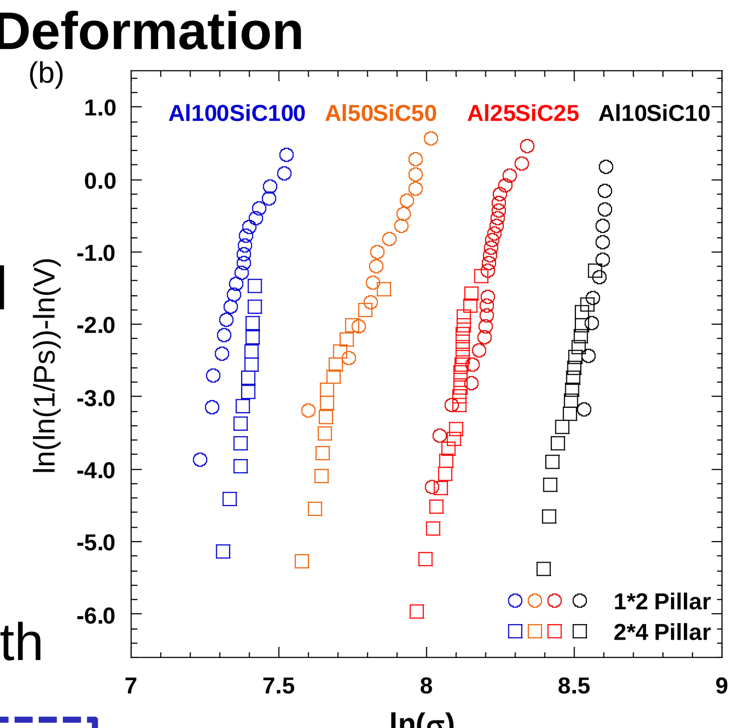

Fig. 8 Weibull plot of the fracture stresses of 1x2 and 2x4 μm pillars (in the 90ºorientation) for Al100SiC100, Al50SiC50, Al25SiC25 and Al10SiC10.

References

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