Dynamically Driven Phase Transformation in Damaged Composite Materials: Micromechanics

JeeYeon N. Plohr, Bradford E. Clements T-1; Frank L. Addessio, T-3

We have developed a theoretical framework to model composite materials when the constituents exhibit viscoplasticity, phase transformation, cracking, and debonding [1,2]. The particular systems we studied are SiC-Ti composites, where Ti undergoes solid-solid phase transformation, SiC cracks, and the interface between these materials debonds. The interplay among these phenomena is complicated and often leads to unexpected materials behavior. In understanding these mechanisms in composite materials, it is crucial to examine them at the micromechanics level. This allows us not only to see the distribution of stress, cracking, and debonding inside the composites, but also to identify the areas where competition among these different physical phenomena occurs. This capability to analyze the micromechanics of the constituents is also useful to validate numerical simulation codes. In this article, we report the following three points that we have learned via micromechanics analysis.

1. Even when the stress in a certain direction is tensile, if the net stress (trace of the stress tensor) is compressive, debonding is inactive. We consider the case of compressive net stress because the phase transformation in Ti is pressure-induced. Still, the contribution from the deviatoric part of the stress can overcome compressive pressure, and the overall stress can be tensile. However, viscoplasticity limits the growth of the deviatoric stress, and all components of the stress eventually become compressive. (See Fig. 1.)

2. Different Ti subcells experience phase transformation at different times and different rates because of the anisotropy caused by SiC subcells. SiC has higher elastic moduli, and the Ti subcells close to SiC subcells are subjected to higher load as a consequence of normal traction continuity. When SiC develops cracks, its effective moduli becomes lower, and the anisotropy in stress distribution among the Ti subcells become weaker. As shown in Fig. 2, Ti subcells show a homogenized phase transformation pattern.

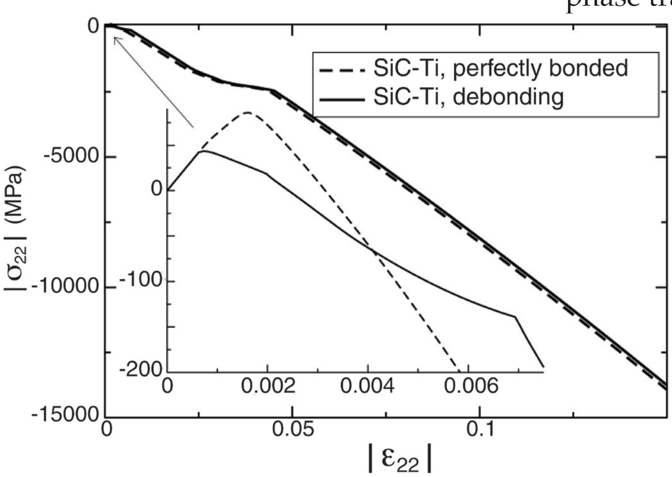

Fig. 1.
The effect of debonding on the material stress-strain behavior. In this simulation, $\dot{\varepsilon}_{11} = -5.0\ s^{-1}$, $\dot{\varepsilon}_{22} = 3.0\ s^{-1}$, $\dot{\varepsilon}_{33} = 0.0\ s^{-1}$.

3. The dependence of stress-strain relationship on the rate of loading is less prominent in damaged composites than in composites without damage. We conclude that this rate desensitization results from the effective homogenization of moduli as the SiC develops cracks. (See Fig. 3.)

For more information contact JeeYeon Plohr at jplohr@lanl.gov.

[1] B. Clements, et al., *J. Appl. Phys.* **100** (12), 123520 (2006).
[2] J.N. Plohr, et al., *J. Appl. Phys.* **100** (12), 123521 (2006).

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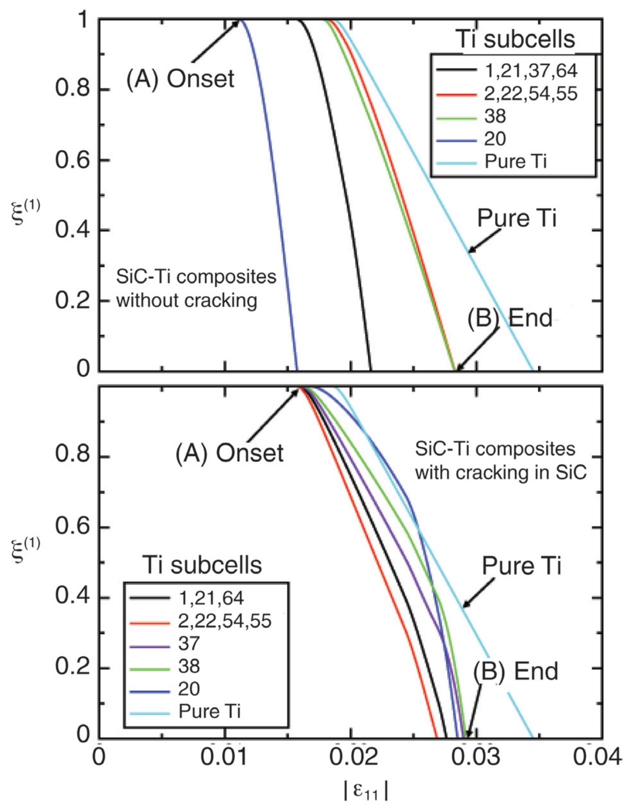

Fig. 2.
The Ti α-phase mass fraction $\xi^{(1)}$ as a function of the macro-strain ε_{11}, for a uniaxial strain loading rate of $\dot{\varepsilon}_{11} = -1.0\ s^{-1}$. Crack growth damage is suppressed (top) and allowed to occur (bottom). Points (A) and (B) indicate the onset and conclusion for the phase transformation in the composite.

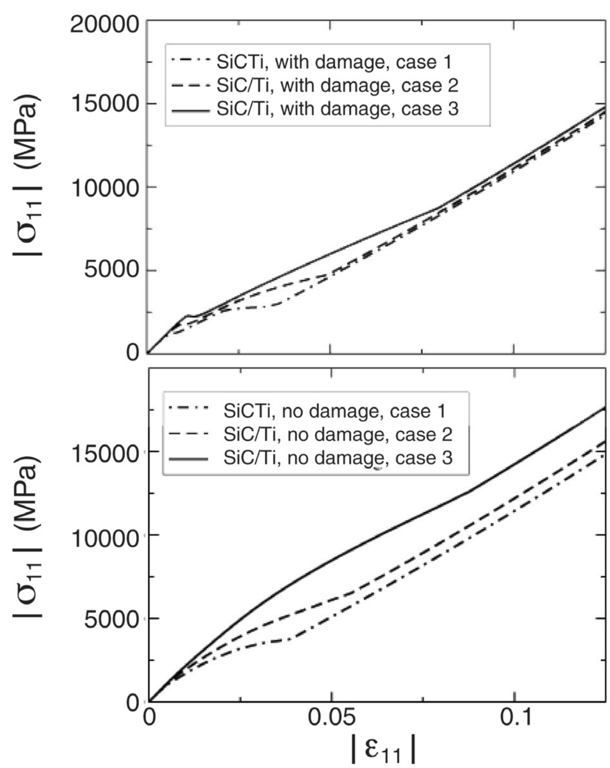

Fig. 3.
The effect of strain rate on the (macro) stress-strain behavior of the undamaged (bottom) and damaged (top) composite. In case 1, $\dot{\varepsilon}_{11} = -100\ s^{-1}$, $\dot{\varepsilon}_{22} = \dot{\varepsilon}_{33} = 10\ s^{-1}$. In case 2, $\dot{\varepsilon}_{11} = -1000\ s^{-1}$, $\dot{\varepsilon}_{22} = \dot{\varepsilon}_{33} = 100\ s^{-1}$. In case 3, $\dot{\varepsilon}_{11} = -5000\ s^{-1}$, $\dot{\varepsilon}_{22} = \dot{\varepsilon}_{33} = 500\ s^{-1}$.