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DEFORMATION AND FRACTURE IN METAL-MATRIX COMPOSITES

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It is commonly acknowledged that stress concentration, plastic strain localization, as well as nucleation of microcracks and microdefects are controlled by the interfaces between the microstructure constituents. The values of microscale strains and stresses developing in the near-interface regions depend, among other factors, on the difference in mechanical properties of the contacting materials. Thus, the microscale stress-strain analysis acquires a particular importance for composite materials characterized by a wide variety of well-defined interfaces between the constituents with clearly distinct properties.

Particle reinforced composites (PRCs), due to their high strength-to-weight ratio, are extensively used in mechanical, power engineering, and aerospace industries. The PRC coatings effectively improve the wear and corrosion resistance and strength of material surface layers. Despite their wide applications, the issues of strength and durability of the present-day composite materials have not been completely solved by now. This is primarily due to their complicated multi-phase structure, which makes the behavior of composites poorly predictable within the traditional single-level approaches and homogenization techniques.

An integrated experimental and numerical study is performed to investigate the deformation and fracture in aluminum matrix – carbide particle composites. Al-TiC and Al-B_4C cylindrical specimens are fabricated by solid-state sintering during hot pressing and then subjected to compression and tension tests for investigating the fracture by electron microscopy. The method of step-by-step packing is adopted to generate 3D model microstructures of metal-matrix composite materials. The dynamic boundary-value problems are solved numerically by the finite-element method using ABAQUS/Explicit. Constitutive models describing the mechanical behavior of the matrix and particle materials, where isotropic strain hardening is included into consideration and a fracture criterion is used, are implemented in the FE calculations through a user-defined subroutine. The interrelated plastic strain localization in the aluminum matrix and crack origination and growth in ceramic particles are investigated under tension and compression of the composites. Debonding and in-particle cracking are found to agree well with the fracture patterns observed experimentally (Fig. 1).

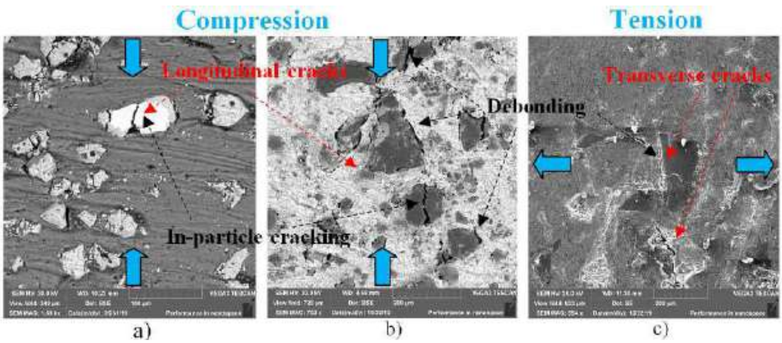

Fig. 1 Cracking of the carbide particles under compression (a, b) and tension of composites (c). TiC (a) and B_4C particles (b, c)

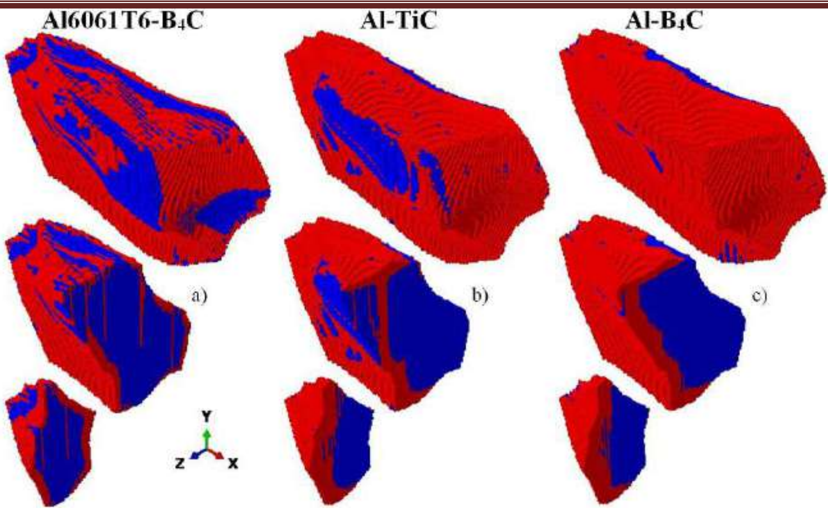

Fig. 2 Calculated fracture patterns (red-colored regions) on the surface and in the selected sections of the ceramic particle for composites in tension along the Z-axis. Strain a) 0.6, b) 4 and c) 18 %

The numerical simulation results suggest the following conclusions.

1. Local regions of bulk tension arise during external compression of the composite material due to the irregular geometry of the matrix-particle interface; they are located in the zones different from those of external tension.

2. Debonding and in-particle cracking are observed both in tension and compression of the composite. The cracks originate in the near-interface regions, experiencing bulk tension, and propagate in different directions – perpendicular to and along the direction of loading, respectively. The fracture is more intensive under tension than under compression.

3. Low yield point of the matrix material and high strength of ceramic particles suppress in-particle cracking and intensify debonding along the matrix-particle interface (Fig. 2).

4. The calculation results are quite consistent with the experimental evidence on the fracture patterns appearing after tension and compression of the composites fabricated by solid-state sintering during hot pressing.

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