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On the brittle fracture characteristics of lamella walls of ice-templated sintered alumina scaffolds and effects of platelets

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A B S T R A C T

We attempted to develop a phenomenological understanding of the evolution of the fracture events within fine-grained lamella walls of partially deformed ice-templated sintered Al_2O_3 scaffolds and revealed the effects of the platelets on the crack propagation characteristics. Detailed microstructural analyses suggest that intergranular cracks within the walls evolved at two orientations, parallel and perpendicular to the loading direction. We proposed probable mechanisms including one based on the so-called wing-crack model to rationalize the observed crack orientations. We presented crack propagation behavior in lamella walls in presence of the platelets and discussed the effects in terms of the crack deflection mechanism.

Uniaxial compressive stress-strain response of ice-templated sintered ceramic scaffolds is akin to that of the cellular ceramics, which features a linear elastic regime, a stress plateau part with a gradual decrease of stress with increasing strain, and a densification stage with a sharp rise of stress with a small increase of strain [1–3]. A general understanding is that inelastic deformation of ice-templated sintered ceramics in the stress plateau regime proceeds through the brittle crushing of the polycrystalline lamella walls [4–6]. There is, however, no detailed study on the fracture characteristics of the lamella walls, which is essential to model the underlying damage-mechanics. It is also important to investigate the effects of the microstructural modifications of the lamella walls on the fracture characteristics, such that their relation to the macroscopic mechanical behavior of the ice-templated ceramics can be understood. The authors have recently investigated the influence of the anisotropic grains (platelets: diameter ~8 μm and thickness ~400 nm) on the microstructure and uniaxial compressive response of highly porous (~80 vol%) ice-templated sintered alumina (Al_2O_3) scaffolds, where the scaffolds were fabricated from the submicrometer equiaxed particles and from the mixtures of the submicrometer equiaxed particles and the platelets [7,8]. Findings of the investigation revealed an unprecedented improvement of the compressive response of the scaffolds containing small volume fraction of platelets relative to the scaffolds without the platelets. In that context, aim of the current study is twofold: (i) shed light into the fracture mechanisms that evolve under the influence of the compressive loading within the polycrystalline lamella walls of ice-templated sintered Al_2O_3 scaffolds containing fine equiaxed grains (~2 μm) and (ii) reveal the influence of the platelets (i.e., the anisotropic grains) present within the lamella walls on the crack propagation characteristics.

A custom-made device was employed to synthesize the ice-templated Al_2O_3 scaffolds, which were processed from the aqueous suspensions containing (a) fine equiaxed Al_2O_3 powder (average diameter 300 nm, referred to here as NA and corresponding scaffolds as NA-scaffolds) and (b) 80–20 vol% mixture of the NA powder and the Al_2O_3 platelets (referred to here as PA and corresponding scaffolds as NA20PA-scaffolds). For each suspension, total Al_2O_3 content was 15 vol%. All the scaffolds were unidirectionally solidified, and average freezing front velocity (FFV) was 30.6 ± 1.8 μm/s and 30.6 ± 1.5 μm/s for the NA-scaffolds and NA20PA-scaffolds, respectively. Frozen scaffolds were freeze-dried at 0.014 mbar pressure and −50 °C for 96 h, and sintered at 1550 °C for 4 h. From each sintered scaffold, a 6 mm × 6 mm × 3 mm specimen was extracted for density measurements, microstructural characterization, and uniaxial compression tests. Sintered specimens were compressed beyond the densification stage to capture the complete uniaxial stress-strain response. However, one specimen from each composition was compressed up to 15% strain and the obtained fragments were analyzed using an SEM to reveal the fracture characteristics within the polycrystalline lamella walls. Further experimental details are provided in the Supplementary Material.

Fig. 1a and b shows the representative SEM micrographs of the top plane of a NA-scaffold and a NA20PA-scaffold, respectively. Pore morphology of the NA-scaffold appears lamellar, whereas the extent of the bridging is observed to have increased significantly in the NA20PA-scaffold and resulted in a dendritic pore architecture. Fig. 1c shows a

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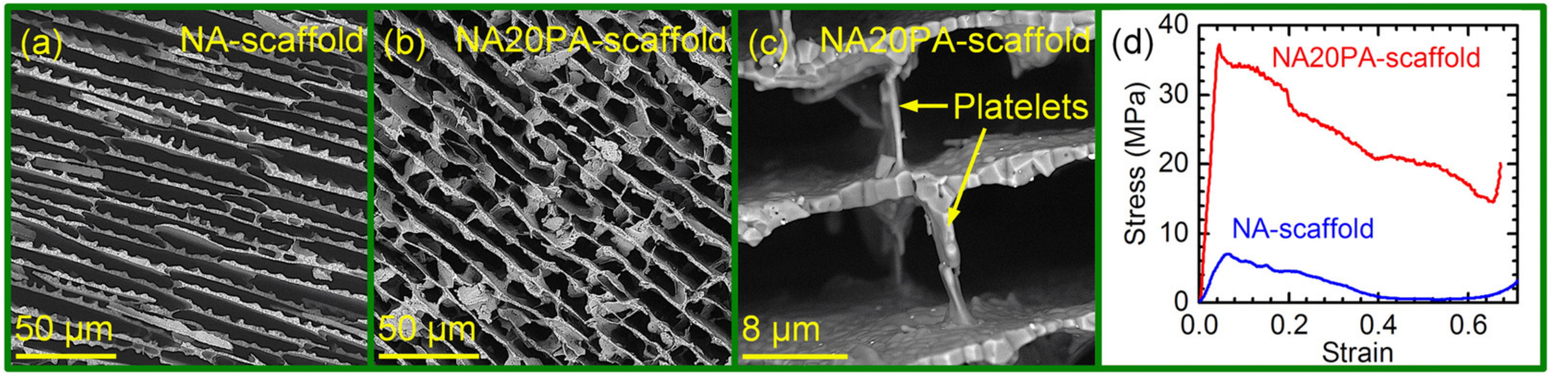

Fig. 1. SEM micrographs reveal (a) lamellar pore morphology of the NA-scaffold and (b) dendritic pore morphology of the NA20PA-scaffold, and (c) high magnification SEM micrograph shows lamellar bridge formation through the platelets (ice-growth direction is out of the page). (d) Comparison of uniaxial compressive response of the NA-scaffold and the NA20PA-scaffold.