Nanoscale deformation and removal mechanisms in heterogeneous composites

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The precision machining of heterogeneous composites is complex and challenging due to the significant characteristic differences of constituent phases. Realizing the deformation and removal mechanisms of heterogeneous composites is essential for processing optimization and parameters formulation. Here, the Al/SiC particle reinforced metal matrix composite was used as an example to conduct nano-scratching test with varying loads (10, 50, 100 and 200 mN). The surface integrity, subsurface damage, and multiscale deformation behaviors were systematically studied. Under the normal load of 10 mN, it was dominated by the plastic deformation of the Al matrix and SiC particles. The deformation mode of SiC particles gradually transformed into brittle fracture with the increase of normal load, with the extent of damage (cracking and fragmentation) intensifying accordingly, and the main features of surface defects were scratches, cracks, surface pits, SiC fragments, and particle pullout. The plastic deformation of Al matrix was mediated by dislocations, with a series of dislocation movements triggering deformation and torsion of Al grains. The Al matrix exhibited diverse deformation mode such as vertical compression, shear deformation, grain extrusion and surface bulging. The plastic deformation and removal process of SiC particle included microcrack generation and deflection, defects production (dislocations and stacking faults), and the amorphization transformation. In the plastic removal process, the deformation of Al grains on the exposed surface would induce geometrically necessary dislocations in adjacent SiC grains to accommodate the strain gradient partitioning. Conversely, the SiC grain on the exposed surface exhibits strong load-bearing capacity but limited deformation ability, thus the Al matrix beneath it was unaffected. In the case of Al plastic deformation and SiC brittle fracture under heavy loads, the broken SiC fragment was extruded into the Al matrix and the Al grains were clearly refined because of continuous and discontinuous dynamic recrystallization mechanisms. This study enhances the understanding of the surface and subsurface formation, nanoscale removal and coordinated deformation mechanisms Al/SiC composites, which can provide theoretical and practical guidance for precision machining of heterogeneous composites.