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TEM Characterization of Dynamic Recrystallization in TiB_2 Particles after Hypervelocity Impact

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Abstract

Characteristic of dislocations and dynamic recrystallization in TiB_2 particles associated with hypervelocity impact craters in 65 vol.% TiB_2/Al composite were investigated by transmission electron microscopy (TEM). As high temperature due to hypervelocity impact can make the dislocation climb, a bunch of vacancies were generated and then gathered to form vacancy slice, finally formed dislocation rings. In addition, by climbing, edge dislocations rearranged themselves into wall vertical with slip plane, which finally forms sub grain boundary. Moreover, big angle grain boundaries were observed, which demonstrates that dynamic recrystal grains were formed in impacted TiB_2 particles. As a result, deformation behavior of TiB_2 particles in 65 vol.% TiB_2/Al composite under hypervelocity impact includes generation of dislocation, slip and climb of dislocation, and dynamic recrystallization.

Keywords

Impact, TiB_2 Particle, Dynamic Recrystallization

1. Introduction

Studies on the microscopic damage of different alloys (including aluminum, titanium, copper, steel, magnesium alloys etc.) subjected to high-speed impact have been reported [1]-[7]. Compared with different alloys, microstructure characteristic of composites after impact should be quite different. Residual microstructures associated

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with hypervelocity impact craters in 55 vol.% TiB_2/2024Al composite were investigated [8]. A new Al_xO_{1-x} phase with the fcc structure and the crystal parameter of 0.69 nm was formed at TiB_2-Al interface.

Four characteristics were found in Al_2O_3 and TiB_2 particles reinforced 2024 Al composite after high speed impact [9]: stacking faults around TiB_2 particle and dislocations within the TiB_2 particle; twins in the Al_2O_3 particle; recrystal grains in 2024 Al matrix; and mixture of amorphous microstructure and nanograins in the matrix. In present paper, 65 vol.% TiB_2/Al composite was fabricated and damage behaviors and residual microstructure of TiB_2 particles were studied.

2. Material and Methods

65 vol.% TiB_2/Al composite target with the diameter of 85 mm and thickness of 15 mm was fabricated using pressure infiltration method [10]. 2024Al alloy spherical projectile with the diameter of 1.5 mm, which belong to the typical size of space debris in the near earth space, was launched from a two-stage light gas gun with the impact velocity of 3.5 km/s. The impact experiment was conducted in air conditioned atmosphere. In present study, sample for transmission electron microscopy (TEM) observation was prepared by the following steps: the slice which is tangent with the bottom of crater as depicted in **Figure 1**, was firstly cut from the target; then it was grinded to 60 μm in thickness. Afterward, a disc with diameter of 3 mm including the region around the tangent point was cut from the slice and ion thinned. TEM was performed on Tecnai G^2 F30 type high-resolution transmission electron microscopy with an accelerated voltage of 300 kV.

3. Results and Discussion

Figure 1 presents the dislocation rings within TiB_2 particles at the bottom of crater in 65 vol.% TiB_2/Al composites impacted by 1.5 mm aluminum projectile with the velocity of 3.5 km/s. Meyers proposed a mechanism for the formation of dislocations in shock-wave deformation of metals [11]. He considered that dislocations are homogeneously generated at the shock front, once the deviatoric stresses exceed a certain critical value. As dislocations were also observed within TiB_2 particles in hypervelocity impacted 65 vol.% TiB_2/Al composites, Meyers' model may also be applied in TiB_2. At the moment of impact between projectile and composite, dislocations were generated. As is known, hypervelocity impact results in high pressure and high temperature. High temperature could let the slip systems operate, which leads to the slipping of dislocation along the slip direction on slip planes. Meanwhile, high temperature could also let the dislocation climb. A bunch of vacancies were generated due to the dislocation climbing and gathered to form vacancy slice. Dislocation rings were formed collapse of vacancy slice, as can be seen in **Figure 1**.

Figure 2 shows parallel dislocation walls in TiB_2 particles after impact. On the condition that electronic beam is parallel with dislocation line, dislocation walls manifested as shown in **Figure 2(a)**. Crystal orientation on two sides of dislocation wall changed slightly. However, on the condition that electronic beam is vertical with dislocation line, dislocation walls manifested as shown in **Figure 2(b)**. Two sets of parallel dislocation walls can be seen on the same crystalline plane. High temperature due to impact made the edge dislocations obtain enough energy to climb. Then edge dislocations rearranged themselves into wall vertical with slip plane, which finally forms sub grain boundary.

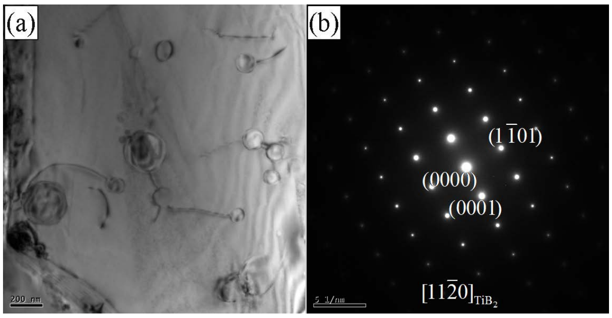

Figure 1. Dislocation rings in TiB_2 particles after impact (a) and corresponding selected area electron diffraction patterns (b).

It can be seen in **Figure 3** that dislocation networks were commonly found within the TiB_2 particles after impact. During the cooling from high temperature and unloading from high pressure after impact, dislocations in TiB_2 particles rearranged and transformed to dislocation networks to lower the defect energy. It can be deduced that formation of dislocation networks should be contributed to the parallel sets of "a" type dislocations ($1/3\langle 11\bar{2}0\rangle$ type dislocations) reacting with parallel sets of "b" type dislocations (<000l> type dislocations) to form "c" type dislocations ($1/3\langle 11\bar{2}3\rangle$ type dislocations) [12]. **Figure 4** reveals that a sub grain formed among dislocation networks in TiB_2 particles. Corresponding selected area electron diffraction patterns of Grain 1 and Grain 2 showed that two grains have low misorientation. Few dislocations can be observed within the Grain 1. However, outside Grain 1, there still appear high density dislocation networks.

Figure 5 displays recrystal grains in impacted TiB_2 particles. After the selected area electron diffraction of Grain 1 and Grain 2, it can be found that the $(\bar{1}10)$ plane of Grain 2 was deflected with 30˚ compared with that of Grain 1. It is to say, orientation difference between Grain 1 and Grain 2 is 30˚. After the selected area electron diffraction of Grain 2, the selected area electron diffraction of Grain 3 and Grain 4 were done on the condition of not tilting the TEM sample. It can be seen from **Figure 5(d)** and **Figure 5(e)**, the center of reflecting sphere changed, demonstrating orientation of Grain 2, Grain 3 and Grain 4 is different. After calculation, orientation difference between Grain 3 and Grain 2 is 3.6˚. Orientation difference between grain 4 and grain 2 is 3.6˚. Orientation difference between Grain 3 and Grain 4 is 7.2˚. From above analysis, grain boundary between Grain 2, Grain 3 and Grain 4 belongs to small angle grain boundary, but grain boundary between Grain 1 and

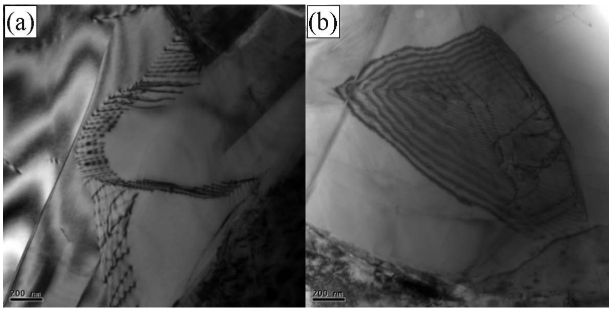

Figure 2. Parallel dislocation walls on the condition that electronic beam is parallel with dislocation line (a) and on the condition that electronic beam is vertical with dislocation line (b) in TiB_2 particles after impact.

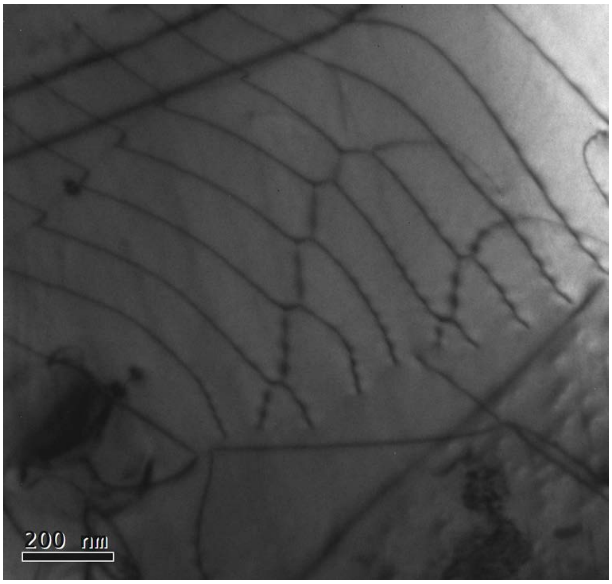

Figure 3. Dislocation networks in TiB_2 particles after impact.

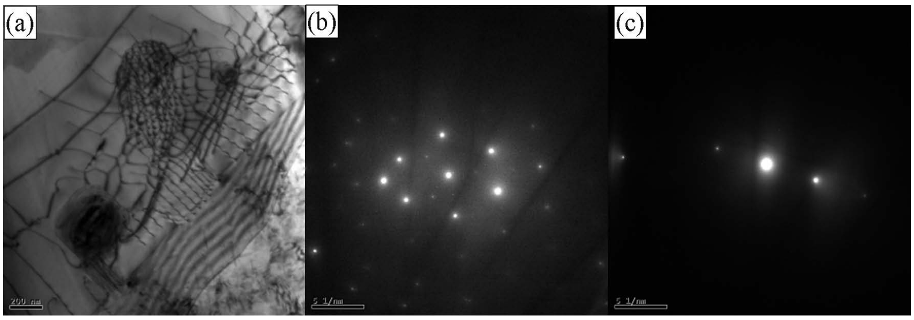

Figure 4. Sub grains in TiB_2 particles after impact (a) and corresponding selected area electron diffraction patterns of Grain 1 (b), Grain 2 (c).

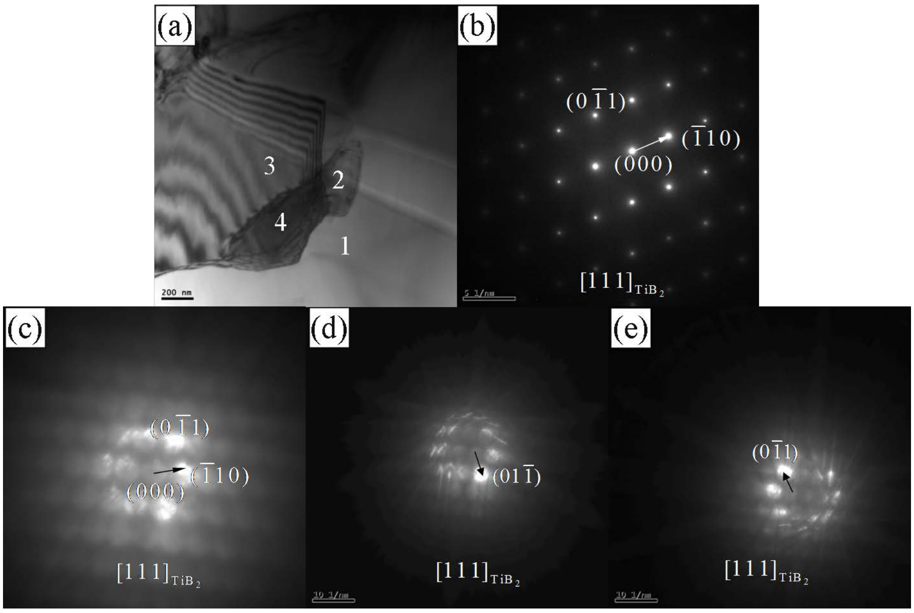

Figure 5. Recrystal grains TiB_2 particles (a) and corresponding selected area electron diffraction patterns of Grain 1 (b), Grain 2 (c), Grain 3 (d), Grain 4 (e).

Grain 2 (or Grain 3 and Grain 4) belongs to big angle grain boundary. As a result, Grain 2, Grain 3 and Grain 4 were dynamic recrystal grains.

It is generally accepted that most ceramic materials (e.g. TiB_2), at room temperature, fail through the process of critical crack growth coupled with fast propagation. The contribution of dislocations to the failure of ceramics is thought to be negligible compared with that of crack propagation. However, in present study, deformation behavior of TiB_2 particles in 65 vol.% TiB_2/Al composite under hypervelocity impact includes generation of dislocation, slip and climb of dislocation, and dynamic recrystallization.

4. Conclusion

Dislocation rings, dislocation walls, sub grains and recrystal grains in impacted TiB_2 particles were observer in present study. It is to say, during the hypervelocity impact and following unloading process, deformation behavior of TiB_2 particles includes generation of dislocation, slip and climbing of dislocation, and dynamic recrystallization.

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