Materials Science & Engineering A 736 (2018) 349–353

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Short communication

The high speed collision induced ultrahard recrystallized pure Ni

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ARTICLE INFO

Keywords:
Nickel
High speed collision
Nanocrystallines
High angle boundaries
Strength

ABSTRACT

The microstructures and strength of pure Ni ball after high speed collision process were investigated. The elongated and equiaxed nanocrystallines with high angle grain boundaries and random grain orientation were formed near the interface position due to high strain and strain rate. Sufficient intragranular recrystallization occurred due to shock induced storage energy. Sufficient recrystallization in the grain interior facilitated to activate dislocation in the process of subsequent deformation and resulted in ameliorated hardness. Moreover, the high angle grain boundaries could effectively impede the dislocation movement, which also significantly enhanced the strength of Ni ball near the interface.

1. Introduction

Severe plastic deformation processes, such as, equal channel angular extrusion, high pressure torsion, accumulative roll bonding and hydrostatic extrusion (HE) usually have a low strain rate [1,2]. while dynamic plastic deformation (DPD) [3], laser shock peening (LSP) [4] and high speed collision [5,6] exhibit high strain rate. The evolution of microstructure and texture for Ni single crystal and Ni polycrystal after HE process were investigated [7]. In fact, plastic deformation at high strain rate naturally occurs in many circumstances, therefore, it's necessary to understand the deformation mechanism of metallic materials at high strain rate. Luo et al. [8] investigated microstructural characteristics of pure Ni subjected to DPD and suggested that the higher strain rate facilitated the formation of more refined and homogeneous spaced low-angle boundaries, therefore, the greater grain refinement in pure Ni was achieved due to subdivision by a high frequency of finely spaced low-angle boundaries. It was also found that the higher strain rate increased the dislocation density and reduced the distance between deformation-induced dislocation boundaries and the HAGBs (high angle grain boundaries) at a constant strain for pure polycrystalline Ni deformed by DPD [9]. The accumulation of dislocations facilitated to form lamellar boundaries and interconnecting boundaries for pure Ni produced by LSP and induced ultrafine laminates and ultrafine grains, and then more dislocations would continue to form in the ultrafine grains and divided the ultrafine grains into nano-scale equiaxed grains [10]. Romankov et al. [11] found that the laminar pure Ni could be transformed into an ultrafine grain via ball collision due to high strain rate. The above findings indicate that the deformation mechanism of pure Ni in high strain and strain rate is also very complicated. It was surprise to find that texturing was also seen in 3-nanometer pure Ni in high compressed stress and strain, indicating dislocation activity could be extended down to a few-nanometers-length scale [12]. Investigating the microstructure-property relationship is challenging for pure Ni in very high strain rate, therefore, the microstructures and strength of pure Ni near the interface between pure Ni and stainless steel after high speed collision were evaluated in this study.

2. Experimental

The 2205 duplex stainless steel bulk was cut into discs and fixed in airtight equipment. Ni balls (1 mm diameter) was placed on one end of a fine stainless steel tube, while the other end was connected with an argon cylinder. Therefore, the impact speed of the Ni ball was adjusted by controlling the pressure of the argon gas. The two sensors in the airtight equipment were used to measure the passing time of the Ni ball. Therefore, the calculated collision velocity of the Ni ball is about 640 m/s. The central position of the Ni ball after high speed collision was analyzed by EBSD (Electron Backscattered Diffraction) measurements by Hitachi SU-70 and the corresponding hardness was measured. The EBSD analysis was performed to investigate the microtexture and IQ (image quality) value. The cross-section of samples was firstly ground using SiC papers (P2500 abrasive) and 1 μm diamond suspension. Then the samples were continuously polished with 0.3 μm and 0.1 μm alumina suspensions. Finally, they were polished using a colloidal silica solution of 0.02 μm. The step size during EBSD data collection was 0.2 μm and 0.02 μm for low and high magnification,

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https://doi.org/10.1016/j.msea.2018.09.022
Received 4 August 2018; Received in revised form 5 September 2018; Accepted 7 September 2018
Available online 08 September 2018

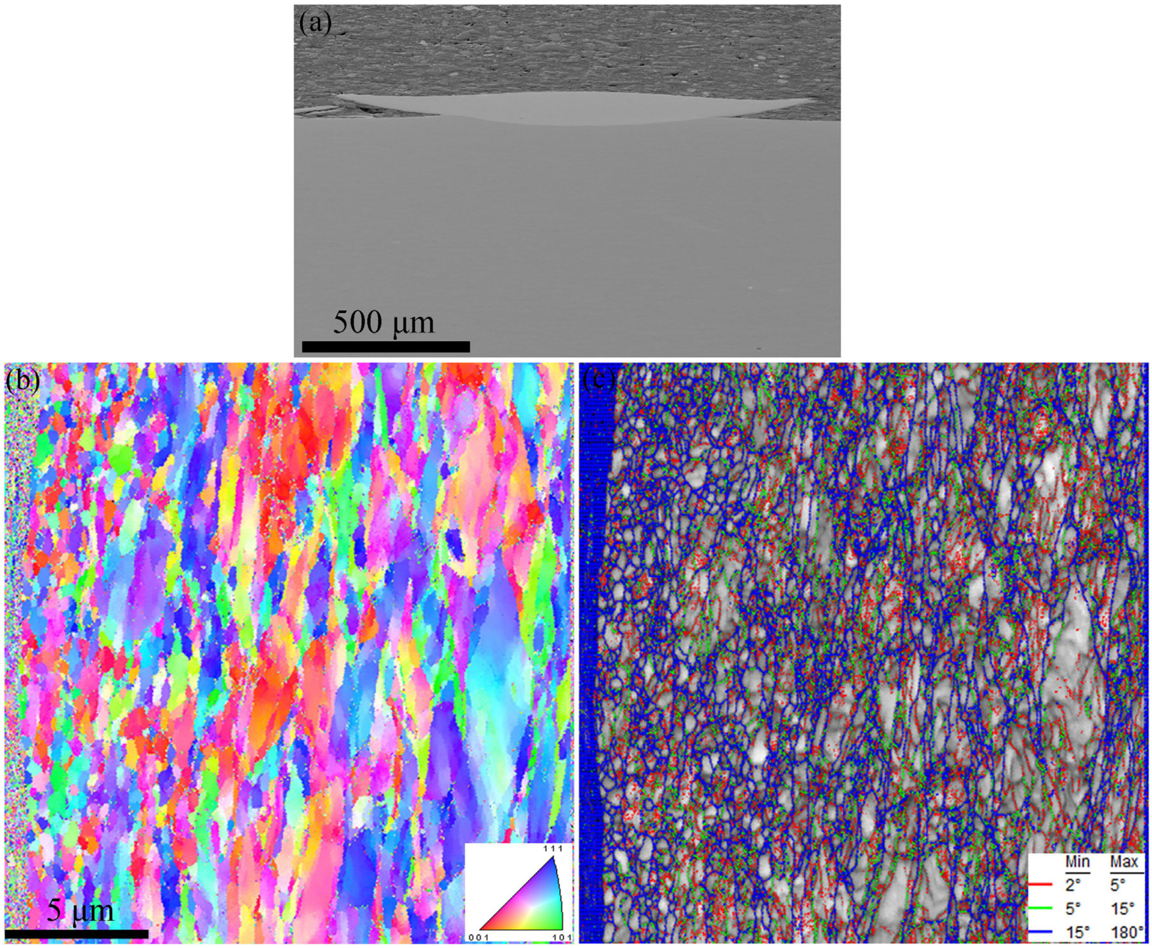

Fig. 1. (a) Schematic morphology after high speed collision, (b) IPF maps and (c) grain boundaries near the interface for pure Ni ball after high speed collision.

respectively. The collected data was analyzed by TSL OIM Analysis 6 × 64 software.

3. Results and discussion

Fig. 1a shows the morphology of pure Ni ball impacted on the surface of duplex stainless steel. Obviously, a depth-dependent gradient microstructure is found for pure Ni in Fig. 1b, and a refined layer close to the interface of 3 μm thick is formed. The severe plastic deformed and elongated grains are observed at the bottom of the refined layer in Fig. 1c. The transition of microstructures could be attributed to different strain levels and strain rates. Moreover, no evident preferred grain orientation is observed. It was found that the HE process induced a heterogeneous and ultrafine-grained microstructure for nickel 200 [13].

Elongated nanolaminated grains are roughly perpendicular to the collision direction in Fig. 2a, moreover, some refined equiaxed grains are also observed in Fig. 2b. The transition of laminated structure to equiaxial crystal structure should be due to higher strain and strain rate. Most of grain boundaries are straight and sharp, indicating the process of dynamic recrystallization is obvious due to high storage energy in the process of high speed collision. However, 2D laminated pure Ni with low angle boundaries and strong deformation textures was obtained by surface mechanical grinding treatment (SMGT) due to high strain rates and high strain gradients which induced extraordinary refined grain [14]. This difference could be attributed to different stress ways, and pure Ni in SMGT was mainly subjected to strong shear stress. In Fig. 2c, the misorientation inside the grains is lower than that in the grain boundaries. The IQ value is the average sharpness of the Kikuchi lines which are formed by the diffraction of an inelastic scattered electron obtained from the measured area in EBSD test. The contrast of Kikuchi lines correlates strongly with the intensity of the diffracted beams and is depending on the crystallinity, i.e., atom arrangement of the measured area. Therefore, the crystallinity level of deformed pure Ni can be effectively evaluated by the IQ value averaged by using the values of the nearby measurement points across the grain boundary [15]. In Fig. 2d, high IQ value inside the grains indicates strong recovery and crystallinity process during high speed collision process.

The misorientation angles near the interface are statistically and analyzed, as shown in insert in Fig. 3a. 76.6% of boundaries have misorientation angle above 15° in Fig. 3a. It was found that HE process facilitated to induce more medium-angle and high-angle boundaries and grain refinement increased for polycrystalline Ni after large strain [16]. The HAGBs are supposed to form with the increasing of strain by a continuous accumulation of boundary misorientation during straining or the grain rotation to different end orientations [17]. It was also suggested that deformation of materials in high strain would end up with the saturation structures with a large fraction of HAGBs [18]. On the one hand, structural refinement should be accompanied by accumulation of misorientation angle between neighboring boundaries, on the other hand, the structural refinement also may probably come to a cease if boundary misorientation angle reaches a saturation value. In addition, local temperature rise and heat generation played a key role during ball collision process [19]. Therefore, the dynamic recovery should play an important role on the determining of microstructural characteristics and the minimum structural size. The point-to origin profile is increasing continuously and slightly in Fig. 3b, which indicates that a small amount of GNDs (geometrically necessary