Materials Letters 173 (2016) 123–126

Contents lists available at ScienceDirect

Materials Letters

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

Evolution of the structure and strength of steel/vanadium alloy/steel hybrid material during severe plastic deformation

S.O. Rogachev [a], R.V. Sundeev [b,c,*], V.M. Khatkevich [a]

[a] National Science and Technology University “MISIS”, Leninskiy prospect 4, 119049 Moscow, Russia
[b] I.P. Bardin Science Institute for Ferrous Metallurgy, 105005, Radio st. 23/9, Moscow, Russia
[c] Moscow Technological University, “MIREA”, Vernadskogo Av. 78, 119454 Moscow, Russia

ARTICLE INFO

Article history:
Received 15 February 2016
Accepted 8 March 2016
Available online 9 March 2016

Keywords:
Severe plastic deformation
High pressure torsion
Nanostructure
Metal hybrid materials
Vanadium alloys
Ferritic corrosion-resistant steel

ABSTRACT

In the present study, severe plastic deformation (SPD) has been used to joint dissimilar materials and form a multilayer hybrid material with nano- and submicrocrystalline structure. The evolution of the structure and strength of steel/vanadium alloy/steel hybrid material during SPD by high-pressure torsion (HPT) has been studied. The HPT of three-layer metal block with from ¼ to 5 revolutions leads to the formation of firm joint of all layers. Deformation twists at steel/vanadium alloy boundaries are observed in the hybrid material subjected to HPT with the number of revolutions $N=1$. After HPT with $N=5$, the fragmentation of all vanadium alloy layer into thinner layers, which are rounded, vortex-like in shape, is observed. In this case, the microhradness of steel layers (measured at the sample midradius) increases by 3.2–3.5 times; the hardness of vanadium alloy layer increases by ~2.0 times.

1. Introduction

At present, the development of materials science is related to designing materials that exhibit a combination of higher properties and wider functionality. This is due to the fact that modern high-technology products and processes make high demands for the materials.

Significant scientific interest of investigators to structural bulk ultrafine-grained nano- and submicrocrystalline materials is caused by specific combination of their mechanical, physical, and functional properties, which differ from those of coarse-grained analogs [1–5]. Recent years are characterized by substantial progress in designing new SPD techniques and improvement of existing methods for the preparation of ultrafine-grained materials; technological conditions of SPD were elaborated, fundamental regularities of the formation of nanocrystalline structure in metallic materials were found, and factors determining the combination of properties of such materials were studied. The range of metallic materials, in which the nano- and submicrocrystalline structure was realized, becomes wider [1,6–9].

A hybrid material is a combination of two or several materials, which is characterized by given geometry, sizes, and arrangement of the materials [10,11]. This allows one to reach the required combination of various properties for concrete engineering functionality. Fiber composites, lattices, sandwich structures, and almost all natural biological materials can be considered as examples of hybrid materials. The designing of hybrid materials allows one to reach the combination of high properties and to increase their functionality [10]. Thus, hybrid materials, the combination of properties of which differ from that of individual components, can be realized by very wide range of ways and can be applied in cardinally different areas.

The use of SPD to form a hybrid multilayer material by joining dissimilar materials, which is accompanied by grain structure refining, is of special interest. For example, a nano-structured aluminum/copper hybrid with a helical architecture has been prepared by SPD. However, in this case, the material was single-layer and composed from aluminum and copper fragments [12]. Studies related to the problem are scanty.

Three-layer steel/vanadium alloy/steel composite material is considered as a structural material for the operation under super heavy service conditions (corrosive media, mechanical stresses, radiation, etc.) [13,14].

The present work is aimed at the systematic study of the evolution of structure and strength of hybrid steel/vanadium alloy/steel material under different HPT conditions.

2. Materials and research methods

The initial flat samples 8 mm in diameter were cut from sheets of $0.08C-18Cr-0.5Ti$ steel and $V-10Ti-5Cr$ alloy in the

---

* Corresponding author at: I.P. Bardin Science Institute for Ferrous Metallurgy, 105005, Radio st. 23/9, Moscow, Russia.
E-mail address: apricisvir@gmail.com (R.V. Sundeev).

http://dx.doi.org/10.1016/j.matlet.2016.03.044
0167-577X/© 2016 Elsevier B.V. All rights reserved.

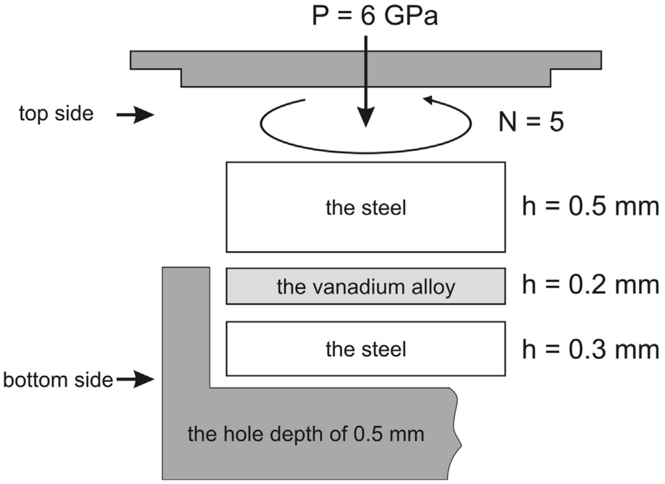

Fig. 1. Schematic diagram of three-layer metal block for HPT.

recrystallized state. The average grain size was (25 ± 4) μm for the steel and (16 ± 6) μm for the alloy. The three-layer block was collected before HPT: bottom steel layer with 0.3 mm thick (near the “hole”), the central layer of the vanadium alloy 0.2 mm thick and top steel layer 0.5 mm thick (in accordance with Fig. 1). HPT of three-layer block was performed in the “hole” with depth of 0.5 mm, at room temperatures, with the quasi-hydrostatic pressure 6 GPa and the 5 number of turns. The quasi-hydrostatic compression of three-layer block was also performed without torsion (N = 0).

The Vickers microhardness in cross section of the samples was measured for analysis of homogeneous of the deformation of the samples after HPT. Measurement of the microhardness was performed with step of 0.5 mm in the direction from edge to the center of the sample and with step of 50 μm in the direction from the top to the bottom surface of the sample. Microhardness measurements with load 0.5 N and holding time 10 s using Micromet 5101.

Electron microscopic studies of the structure of each layer of the hybrid material were performed using a transmission electron microscopes JEM-2100 and JEM 200CX (JEOL). To prepare foils of disk-shaped HPT-samples, one of its layers was thinned to a thickness of ~100 μm by mechanical grinding. After that, disks 3 mm in diameter were cut by ultrasonic cutting and subjected to jet electropolishing at 20 °C using a Struers Lectropol-5 system, a voltage of 20–30 V, and an A2 electrolyte containing perchloric acid, ethanol, 2-butoxyethanol, and distilled water. The final polishing was performed using an ion gun.

Analysis of the structure and the distribution of chemical elements (the concentration maps and profiles) in cross sections of hybrid material were performed using scanning electron microscope JSM-6610LV (JEOL) with electron microprobe analyzer and back-scattered electron mode.

3. Results and discussion

Fig. 2 shows SEM micrographs of cross-section of the hybrid material produced by HPT. Bright and dark areas correspond to the 0.08C – 18Cr–0.5Ti steel and V-10Ti-5Cr alloy, respectively. It is seen that, when the three-layer metal block is subjected to HPT with numbers of revolution of from ¼ to 5, the formation of firm joint without pores and exfoliation. Already after HPT with N = 1, deformation twists form at steel/vanadium alloy boundaries (see Fig. 2b).

After HPT with N = 5, the fragmentation of all vanadium alloy into thinner layers takes place; the layers are rounded, twisted in shape. As the distance from the sample center increases, their number increases and thickness decreases (see Fig. 2c). This fact can be related to peculiarities of shear strain during HPT, its

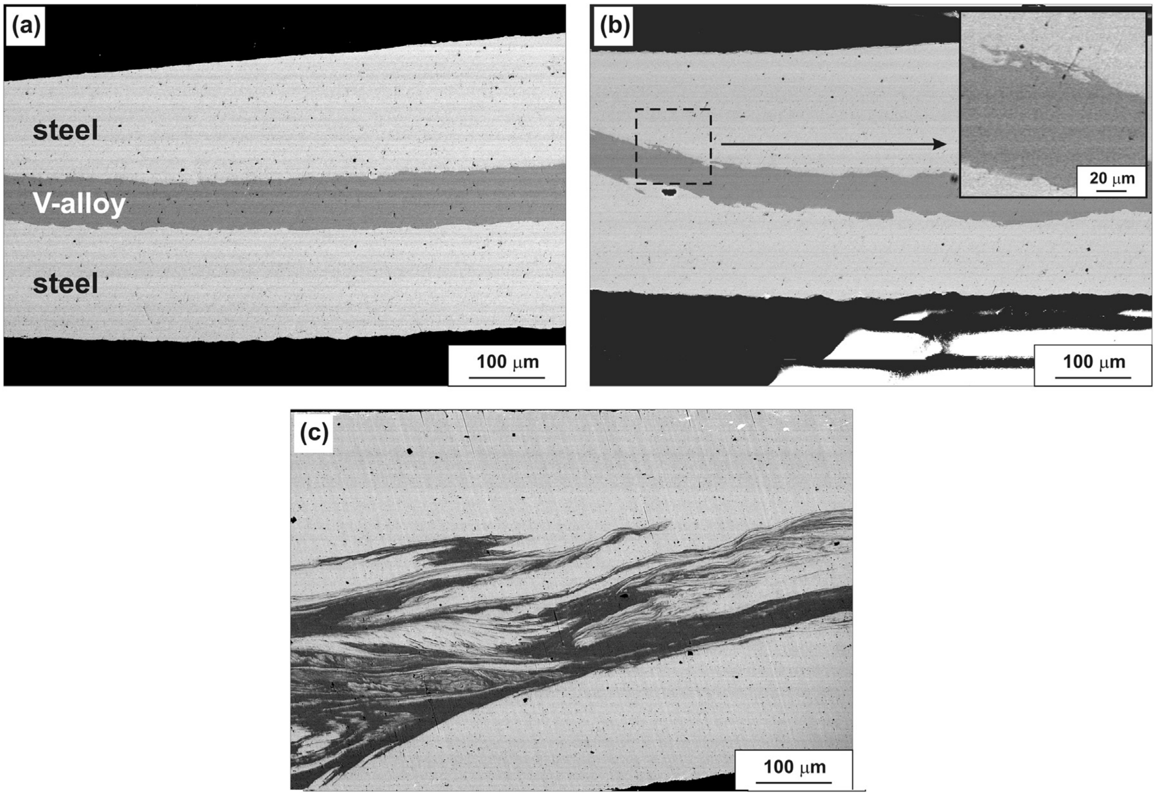

Fig. 2. Micrographs of the cross-section of three-layer hybrid after HPT at 20 °C with different number of revolutions N: (a) ¼; (b) 1; and (c) 5.