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Deformation characteristics of the 93W–4.9Ni–2.1Fe tungsten heavy alloy deformed by hydrostatic extrusion

Zhao-Hui Zhang *, Fu-Chi Wang, Shu-Kui Li, Lu Wang

School of Material Science and Technology, Beijing Institute of Technology, Beijing 100081, PR China

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Abstract

The microstructures evolution, the mechanical properties and the fracture characteristics of the 93W–4.9Ni–2.1Fe tungsten heavy alloys deformed by hydrostatic extrusion with an equal-strain contour concave die were investigated. The strengthening mechanism of the extruded specimens was characterized using a quantitative metallographical technology, scanning electron microscope and a 200 kV transmission electron microscope. Through the research it can be concluded that the increase of the dislocation density in tungsten grains and in matrix, the appearance of the sub-grains in tungsten grains, the decrease of the axial contiguity of the tungsten grains, the increase of the tungsten grain's cleavage proportion in fracture aspect of tungsten alloy are the main factors to strength tungsten alloy.

Keywords: Hydrostatic extrusion; Tungsten heavy alloy; Deformation structure; Mechanical properties; Dislocation

1. Introduction

Tungsten heavy alloys (WHAs) are high-density structural alloys used extensively for kinetic energy penetrators, counterbalance weights, radiation shields and electrical contacts [1,2]. The alloys are a kind of two-phase microstructure of spherically shaped tungsten particles with bcc structure distributed homogeneously in the Ni–Fe–W matrix with fcc structure, and generally fabricated by liquid phase sintering process above 1460 °C [3,4]. For the penetrators, the higher dynamic strength is needed to satisfy the demand of higher shooting velocity, the sintered tungsten alloy cannot always meet the demand, the deformation strengthening process is needed. As a general deformation technology for tungsten alloy, swaging is always used to deform the alloy. But the main limitation of the technology is that the deformation amount for tungsten alloy cannot exceed 20% due to its obvious asymmetry-deforming characteristic. Compared with the swaging technology, the deformation strengthening effect by hydrostatic extrusion is outstanding [5].

The process of hydrostatic extrusion has gained great publicity in recent years because of its simplicity and low cost. In this process, the billet is extruded through a die by a pressurized fluid rather than by a punch or plunger as in conventional extrusion. This slight change in principle results in significant technical advantages over the convention process [6,7], so the technology is applicable to deform metal with higher brittleness and strength such as tungsten alloy.

In this paper the deformation structure and the mechanical properties of the tungsten alloy deformed by hydrostatic extrusion are studied, the dislocation aspects in the tungsten grains and in the matrix, the fracture aspects of tungsten alloy with different deformation amounts are obtained, the deformation strengthening mechanism is discussed.

2. Experimental procedure

The basic features of the hydrostatic extrusion process for deforming tungsten alloy have been investigated using the apparatus shown in Fig. 1. This apparatus, in which pressures of up to about 1600 MPa was used, and pressure was increased stepwise. Following each step (about 0.5 MPa), pressure was held constant for about 3 min, and increased again if no extrusion effect was observed. The die with an equal-strain contour concave shown in Fig. 2 was adopted according to the principle of minimum extrusion pressure and the even stress–strain contour distribution in specimen.

* Corresponding author. Tel.: +86 10 68912712 803; fax: +86 10 68913951 88.
E-mail address: zhang@bit.edu.cn (Z.-H. Zhang).

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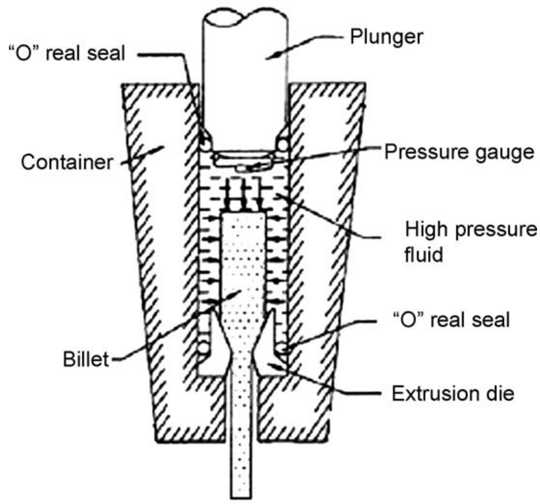

Fig. 1. Hydrostatic extrusion apparatus.

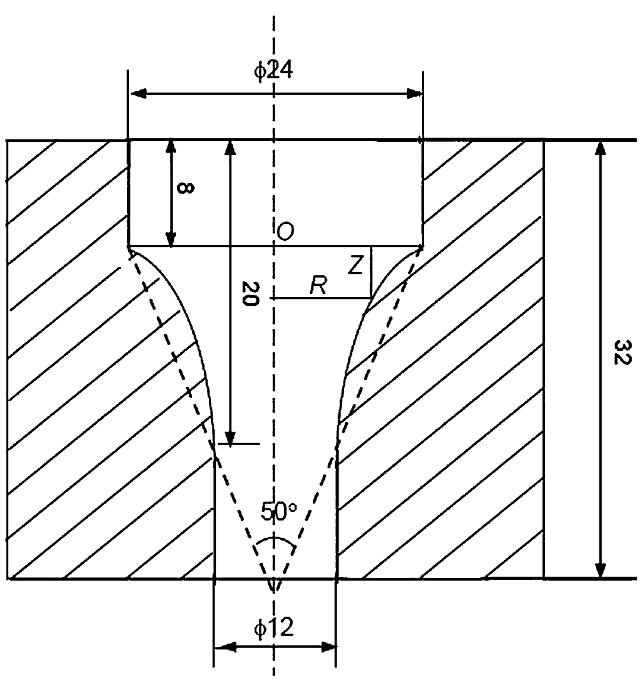

Fig. 2. Geometrical sketch of die.

The tungsten powders 3.0 μm, nickel powders 2.5 μm and iron powders 2.5 μm in average diameter of particle size were mechanically alloyed in an attritor mill to process the tungsten heavy alloy with the composition of 93W–4.9Ni–2.1Fe in weight percent. The powders MA-ed for 60 h were consolidated into green compacts by cold isostatic pressing under 200 MPa. The compacts were sintered at 1150 °C for 90 min in hydrogen atmosphere, the solid-state sintered WHA was subsequently liquid-phase sintered, again at a temperature of 1470 °C for 60 min. The sintered WHA was heat-treated at 1100 °C for 3 h to eliminate hydrogen. The produced tungsten alloy was hydrostatically extruded. The deformation amount is selected as 28%, 59% and 85%. The deformation structure and strengthening mechanism of the extruded specimens were characterized using a quantitative metallographical technology, scanning electron microscope (SEM, JSM-5600LV) and a 200 kV transmission electron microscope (TEM, JEM-2000FX). The static mechanical properties of extruded specimens were tested using the uniaxial servohydraulic testing machine (Instron 5580) with a tensile velocity of 0.5 mm/min, and the dynamic mechanical properties were tested by SHPB-Split Hopkinson Pressure Bar apparatus.

3. Results and discussion

3.1. Deformation structure and mechanical properties

Fig. 3 shows the deformation structure of the 93 W alloy deformed by hydrostatic extrusion, from which we can see that the tungsten grains are global and well immersed in the matrix before deformation, while after deforming the tungsten grains became ellipsoidal and the matrix was extruded into strip. The deformation effect of the deformation structure became more evident along with the increase of the deformation amount, the fibrous deformation structure appeared when the deformation amount reaches 85%.

Fig. 4 shows the static and dynamic mechanical properties of 93 W alloy with different deformation amounts. Where σ_s and δ_s denote the static tensile strength and the static elongation respectively, σ_d and δ_d denote the dynamic tensile strength and the dynamic elongation respectively at a condition of 1000 s^{-1} strain rate. From which we can see that the static tensile strength and the dynamic tensile strength increase, the static elongation and dynamic elongation decrease along with the increase of

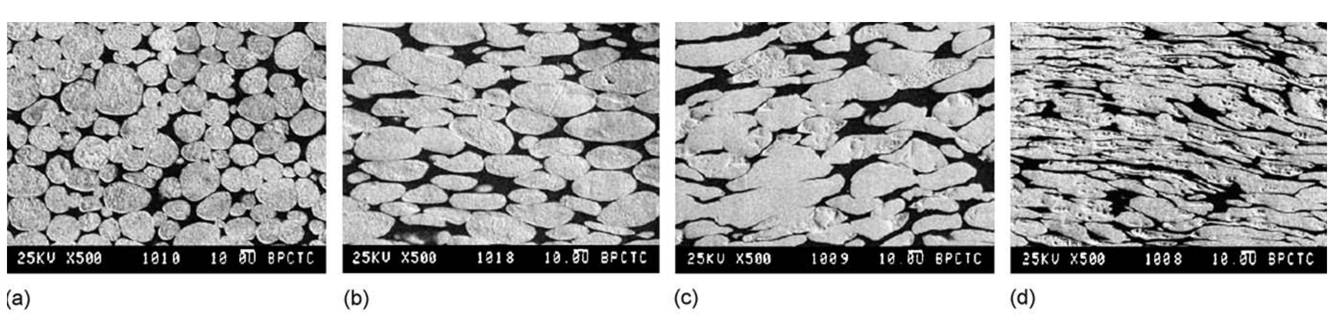

Fig. 3. Deformation structure of 93 tungsten alloy deformed by hydrostatic extrusion. (a) As-sintered; (b) deformed by 28%; (c) deformed by 59%; (d) deformed by 85%.