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Compressive behavior of liquid phase sintered 90 W-7Ni-3Fe heavy alloy at high temperature and low strain rate condition

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ABSTRACT

The compressive behavior of 90 W-7Ni-3Fe heavy alloy prepared by liquid phase sintering is investigated systematically at strain rates 0.001, 0.01 and 0.1 s^{-1} and temperatures 298, 1073, 1273 and 1473 K. Compressive yield strength of the material increases with the increase of strain rate and decreases with the increase of temperature. The compressive deformation is affected by the coupling of work hardening and thermal softening; plastic deformation is dominated by work hardening at 298, 1073 and 1473 K below strain 0.5; plastic deformation is dominated by work hardening at 1473 K below strain 0.2. The work hardening rate decreases with the increase of strain and then tends to a relatively stable level. Microstructure evolution is sensitive to temperature and strain rate. The mechanical properties of specimen deteriorated significantly and the abnormal growth of W particles occurs at low strain rate (0.001 s^{-1}) and high temperature (1473 K). The shear band with angle of about 45° to the compression direction appeared at the corner of samples at 1073 K. A large number of defects on phase interface appeared due to inconsistent deformation.

1. Introduction

Tungsten heavy alloys (WHAs) have a typical two-phase microstructure consisting of nearly spherical shaped bcc tungsten particles homogeneously embedded in an fcc Ni/Fe matrix phase. It has excellent properties such as high strength, moderate ductility, radiation shielding and outstanding thermal conductivity. Due to its unique combination of mechanical and thermal properties, WHAs are used as counter weights, radiation shields, rocket nozzles and military applications [1, 2]. In particular, WHAs are seen as attractive candidate materials for using as kinetic energy penetrators instead of the depleted uranium alloys (DUAs) [3]. Compared with DUAs, WHAs have the advantages of no toxicity and no radiation pollution. However, WHAs are prone to form "mushroom-like head" to reduce lethality. Therefore, to improve the over-all properties of WHAs is a long-term focus in the future.

A large number of researches have been conducted to examine mechanical properties and microstructure evolution of WHAs in the past several decades. Different preparation technologies have been adopted to improve the mechanical properties of WHAs. Fan J et al. [4] investigated the dynamic behavior of conventional 93 W-4.9Ni-2.1Fe alloy and fine-grained 93 W-4.9Ni-2.1Fe alloy respectively. They found that the fine-grained WHAs exhibit higher strength and ductility. The emergence of obvious adiabatic shear bands in the fine-grained WHAs under relatively lower strain rate indicates that the susceptibility to shear localization is enhanced substantially by grain refinement. Jiten Das et al. [5] investigated room temperature and high temperature flow behavior of W-7.1Ni-1.65Fe-0.5Co-0.25Mo alloy at different strain rates (1–0.0001 s^{-1}). The heavy alloy can withstand 70% compressive deformation without failure at room temperature and could be deformed without cracking up to 400 °C. The strength of the alloy increases significantly after the compressive deformation. Therefore, the alloy could be strengthened to a large extent by compressive deformation such as swaging. WS Lee et al. [6, 7] investigated the effects of strain rate and temperature on flow behavior of 92.5 W-5.25Ni-2.25Fe alloy by liquid phase sintering. The results demonstrated that flow stress of W-Ni-Fe composite increases with increasing strain rate and decreasing test temperature. Q Wei et al. [8] found that true stress-true strain curves of ultra-fine grained WHAs exhibited significant flow softening, and the peak stress was up to 3GPa. G Prabhu et al. [9] and W Liu et al. [10] investigated microstructural evolution, tensile and impact properties of microwave sintered WHAs. The results showed that microwave sintered alloy exhibited fine tungsten particle size and low contiguity, resulting in excellent impact properties. A lot of numbers of studies found that tungsten heavy alloy was both temperature and strain rate sensitive. The effect of an increasing strain rate was a slight strength increase with an accompanying ductility decrease [11]. With the increase of the test temperature, the strength such as bending strength, yield strength, tensile strength and fracture strength decreased, the ductility increased

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Table 1
Purity and average particle size of elemental W, Fe, Ni powders.

Powders	Purity, wt%	Average particle size, μm	Major impurities, wt%		
			C	O	P
W	99.9	3.0	< 0.01	< 0.08	–
Ni	99.5	5.0	< 0.10	< 0.10	< 0.0005
Fe	99.5	5.0	< 0.02	< 0.20	–

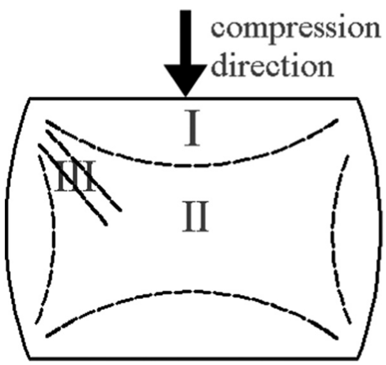

Fig. 1. Cross-section of compressed samples.

slightly and then decreased, and the strain rate sensitivity decreased [12–15]. Sintering temperature was also an influencing factor on tungsten heavy alloy. Studies have shown that with increasing sintering temperature, there were an increase in strength and grain size and a decrease in hardness [16, 17].

Lots of large plastic deformation experiments have been performed to improve mechanical properties of tungsten heavy alloy. Levin Z S et al. [18] found that hardness of 90 W-8Ni-2Fe increased to 50HRC and the tungsten grain size could be refined to submicron grade. Yu Y et al. [19] and Durlu N et al. [20] investigated effect of swaging on the microstructures and mechanical properties of WHAs. There was a notable increase in tensile strength and microhardness and a reduction in ductility by swaging. After swaging, the residual stresses were present confirmed by grain misorientations analyses, which were distributed in the matrix phase and W particles peripheries [21, 22]. Gong X et al. [23] studied tensile behavior of rapidly hot-extruded W-Ni-Fe alloys. Results showed that ultimate tensile strength and hardness could be markedly increased but with a decrease elongation. Hot hydrostatic extrusion [24, 25] and hydrostatic extrusion [26, 27] were used to strengthen WHAs. Results showed that they can improve the strength and ensure good ductility of WHAs. Thus it could be seen that hydrostatic extrusion and hot hydrostatic extrusion were good means to strengthen properties of WHAs. Researches above on WHAs in recent years focus on how to obtain higher mechanical properties. However, armor piercing is a complex process, which is affected by temperature, strain rate and stress - strain field and so on. Therefore, only improving the strength of WHAs cannot meet the demand of the armor piercing projectile for optimum design and high armor piercing power. The mechanical behavior and microstructure evolution of WHAs based on strain rate and temperature (room temperature and elevated temperatures) is studied to simulate the armor piercing process, which can provide experimental evidence and theoretical basis for subsequent thermal processing and improvement of armor piercing power.

In this paper, the 90WHAs prepared by liquid phase sintering were conducted uniaxial compression tests in room temperature and elevated temperatures. Microstructure examinations, SEM analyze and hardness measurement were then performed to evaluate the mechanical properties and microstructure evolution. The effect of strain rate and temperature on deformation behavior is investigated in detail. The nature of the microstructure evolution, the strain hardening and thermal softening effects are interpreted systematically in terms of the testing conditions simultaneously. These data may be useful for the improvement of service performance, numerical simulation, and the parameters optimization of plastic deformation technologies.

2. Experimental procedures

Elemental powders of reduced tungsten, carbonyl nickel and carbonyl iron used in this study were weighted according to the designed chemical compositions of 90 W-7Ni-3Fe. The characteristics of the starting materials are listed in Table 1. The 90 W-7Ni-3Fe alloy was fabricated by liquid phase sintering with blended element powders of

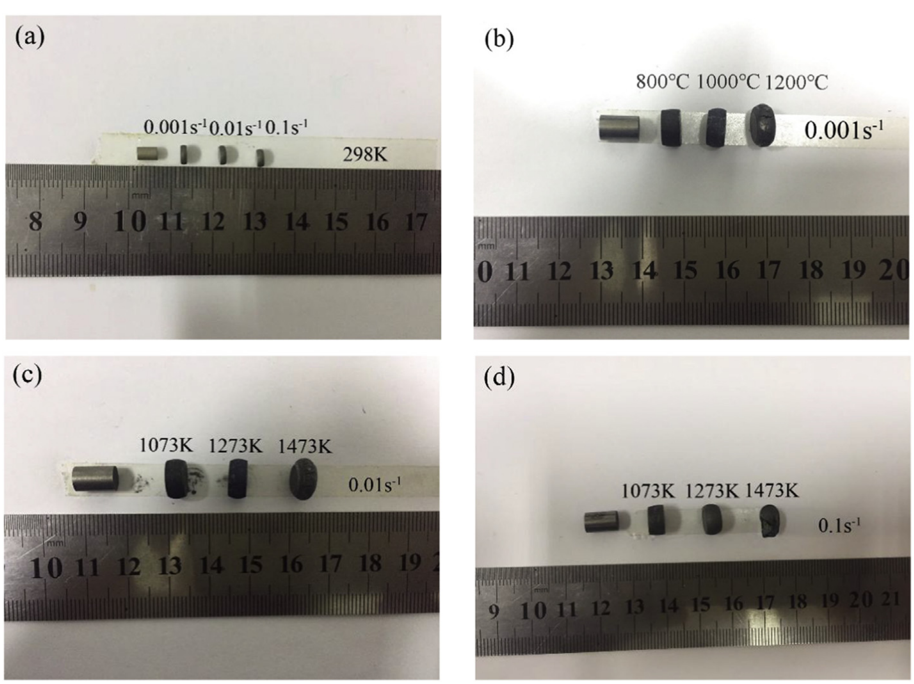

Fig. 2. Photographs of specimens after compression tests at different temperatures and strain rates.