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FUSION-9514; No. of Pages 8
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

Influence of high-temperature ion irradiation on microstructures of the deformed and heat-treated V-4Cr-4Ti alloy

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HIGHLIGHTS

- Deformation and heat-treatment stabilize cooperatively the alloy under irradiation.
- The orientation of irradiation induced precipitates (Vanadium Carbide) is random.
- The dislocation networks in the aged sample can remain partially after irradiation.

ARTICLE INFO

Article history:
Received 29 October 2016
Received in revised form 5 May 2017
Accepted 6 May 2017
Available online xxx

Keywords:
V-4Cr-4Ti alloy
Ion irradiation
Cold deformation
Heat-treatment

ABSTRACT

As one of candidate structural materials for future fusion reactors, vanadium alloy has been widely studied in recent decades. In the present investigation, an attempt was made to determine the influence of high energy ions irradiation on the microstructures of V-4Cr-4Ti alloy which had been subjected to aging, cold deformation and heat-treatment. To achieve the aim, aging and cold reduction were carried out, followed by isothermal heat-treatment at 1100 °C for different time. Hardness measurement, optical and electron microscopies were employed to characterize microstructures of the samples. It was found that Ti-rich precipitates coherent to the matrix occur during aging. In the deformed samples, dislocation movement are inhibited by the precipitates, from which dislocation-precipitates interaction are formed. After 550 keV Fe^{10+} irradiation at 500 °C, a lot of voids, dislocation loops and fine precipitates occur in the alloy. The orientation of irradiation induced precipitates (Vanadium Carbide) is random. The sizes of voids are smaller in the annealed samples. The dislocation networks in the aged sample can remain partially after irradiation, due to pinning effect of precipitates formed during aging.

1. Introduction

The vanadium alloy has been recognized as a leading candidate structural material for future fusion reactors, since its low activation, high thermostability and high resistance to irradiation damage [1,2]. In recent decades, a number of efforts [3–6] have been devoted to determining influence of irradiation parameters, such as energy of incident particles, irradiation doses and temperature, on microstructures of the alloy, while little attention has been put on action of deformation and heat treatment before irradiation.

Due to lacking of solid transformation of vanadium alloy matrix, aging, deformation and annealing play a key role on improving microstructures and mechanical properties of the alloy. Some attempts have been made to enhance microstructure and mechanical properties of the alloy using various thermos-mechanical methods [7–9]. Annealing after cold deformation has been employed to refine the coarse grains through static recrystallization [10–12]. However, it is still unclear if these changes introduced by deformation and heat treatment can be kept during irradiation of high energy particles.

In the present study, the V-4Cr-4Ti alloy is aged at 800 °C, then compressed at room temperature to different reduction, followed by annealing at 1100 °C. Finally, the above samples are irradiated by 550 keV iron ions at 500 °C. By comparison of microstructures of samples before and after irradiation, it is expected to reveal the evolution of microstructure of V-4Cr-4Ti alloy during aging, deformation, annealing and irradiation.

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http://dx.doi.org/10.1016/j.fusengdes.2017.05.030

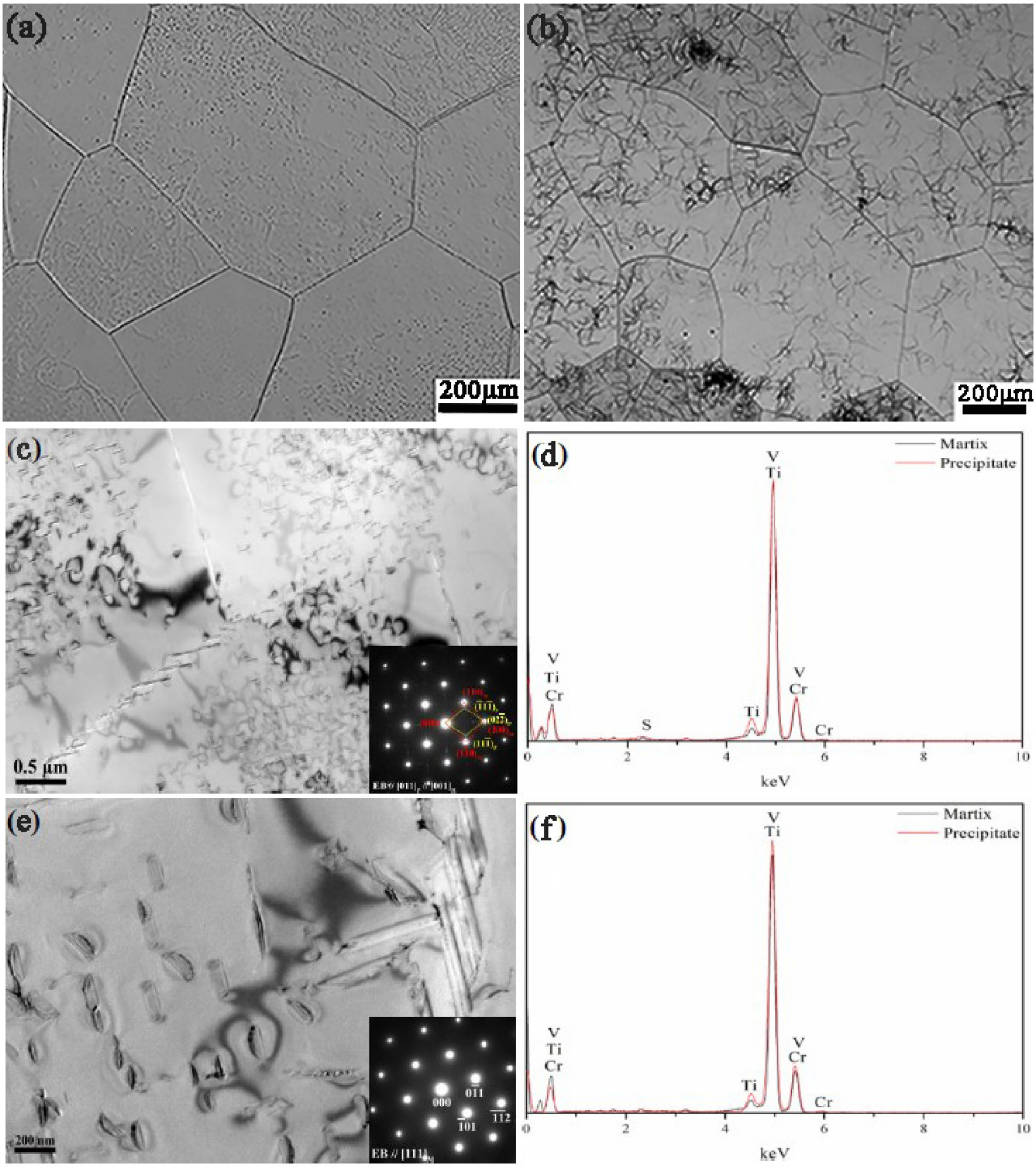

Fig. 1. The OM, TEM and EDS images of the as-cast or the aged samples. (a) OM image of the as-cast sample, (b) OM image of the sample aged at 800 °C for 5 h, (c) TEM image of the aged sample when corresponding electron diffraction is under [001] orientation, (d) corresponding EDS of the matrix (black) and the precipitates (red) for (c), (e) TEM image of the aged sample when corresponding electron diffraction under [111] orientation, and (f) corresponding EDS of the matrix (black) and the precipitates (red) for (e). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

The V-4Cr-4Ti alloy was prepared by method of vacuum arc consumption-self electrode remelting. The chemical compositions of the alloy ingot are 4.48 wt% Cr, 3.92 wt% Ti, 220 ppm C, 250 ppm N, 1000 ppm O and V balanced. The cylindrical samples with ϕ10 mm × 10 mm were cut from the ingot and isothermally aged at 800 °C for 5 h. Some of the aged samples were reduced for 30%, 50% and 70% at room temperature (RT). Annealing was carried out at 1100 °C for 1 h for some of deformed samples. In all heat treatment experiments, samples were tightly wrapped up by the Zirconium foils and then encapsulated into vacuum (<10^{-5} Pa) quartz tubes to avoid oxidation.

The samples for transmission electron microscope (TEM) observation were polished mechanically to a thickness about 100 μm and then punched into discs with a diameter of 3 μm. The discs