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Investigation on mechanical alloying process for vanadium alloys

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ABSTRACT

Mechanical alloying (MA) is an efficient approach for fabricating particle-dispersion alloys, and has recently been introduced to strengthen structural materials including vanadium alloys for fusion application. Dissolution behavior of the alloying elements is a key issue for optimizing MA in fabricating particle-dispersion vanadium alloys. This paper studies the MA process for V–4Cr–4Ti alloys with Y addition. The result shows that, in V matrix, the dissolution rate of Y is higher than that of Cr, and the dissolution rate of Cr is higher than that of Ti. In addition, dissolution of milling ball material and dispersion particles can harden the MA-fabricated alloy.

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1. Introduction

Vanadium alloys, especially those with compositions of V–4Cr–4Ti, are attractive structural materials for a self-cooled liquid Li blanket in fusion reactors [1,2]. As energy conversion efficiency of the blanket increases with increasing operation temperature, enhanced high-temperature strength of the blanket components is a major research goal.

In previous studies, V–4Cr–4Ti was strengthened by increased Cr [3,4] or additions of other elements as solid-solution hardening agents. Also some studies focused on strengthening by thermomechanical treatments, which include work hardening and precipitation hardening processes [5–8]. High density of Ti-(CON) precipitates is the key factor in thermomechanical strengthening. However, from the Gibbs free energy point of view, TiO and TiN are easier to form and thus are coarser than TiC. Accordingly, the sizes as well as distributions of O-rich and N-rich Ti-(CON) precipitates are more variable than those of C-rich Ti-(CON) precipitates. Moreover, during Li exposure, O will transfer from the V–4Cr–4Ti alloy into Li [9,10], making the precipitation conditions more complex and unstable. Some recent studies showed that a vanadium alloy containing V_2C dispersoids has higher thermal stability than those containing Y_2O_3 and YN [11,12]; thus it is expected that carbides will be more stable than the other precipitates.

Grain size refining and nanoparticle dispersion by using mechanical alloying (MA) can efficiently strengthen vanadium alloys. Recently, researchers examined V, V–Cr, V–Ti and V–W systems with Y additions [12–16]. A study on the MA process was carried out for V matrix with Y addition [17], and Kurishita et al. [11] even referred to the potential use of contamination from WC milling balls. V–4Cr–4Ti alloy is believed to be more suitable than the above alloy systems because Ti can promote low swelling [18] and Cr enhances oxidation resistance as well as solid-solution hardening. However, V–4Cr–4Ti has not been used as a matrix system for MA yet. Additionally, in most cases, oxides instead of carbides were regarded as the dispersion particles. In those efforts, the effects of particle dissolution on mechanical properties were not well clarified. In particular, the MA process for multicomponent vanadium alloys needs systematic investigation.

This paper studies the use of MA for V–4Cr–4Ti alloys with 1.5 wt% Y addition and carbide particles. Based on the lattice parameter change and alloying element distributions in the V matrix, the dissolution behaviors of the alloying elements are discussed toward optimization of the MA process for V–4Cr–4Ti alloys. The dissolution effects of milling-ball materials and carbide dispersoids on the hardness of MA-fabricated V–4Cr–4Ti alloys are also discussed.

2. Experimental

The powders used in this study include vanadium (99.9%, 100 mesh), chromium (99.9%, 100 mesh), titanium (99.9%, 100 mesh), yttrium (99.9%, 20 mesh), TiC (99.5%, ~200 mesh), SiC (99.5%, ~200 mesh) and Ti_3SiC_2 (~99.5%, ~200 mesh). The necessary amount of yttrium depends on the O and N impurity levels in the starting powders, which is selected to be 1.5 wt% in the present study assuming most of the O and N are scavenged from the V matrix by the formation of yttrium oxides and nitrides. The powders are mixed to yield compositions of V–4Cr–4Ti–1.5Y–0.3XC in a helium atmosphere (99.9999%), where XC is dispersed carbide. A

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Table 1
Sample arrangement for MA of V–4Cr–4Ti alloys.

No.	ID	Compositions	Material of MA vessel and balls	MA process time (h)
0#	Base, WC, 10hr	V–4Cr–4Ti	WC–Co	10
3#	-SiC, WC, 4hr	V–4Cr–4Ti–1.5Y–0.3SiC	WC–Co	4
5#	-TiC, WC, 4hr	V–4Cr–4Ti–1.5Y–0.3TiC	WC–Co	4
6#	-Ti_3SiC_2, WC, 4hr	V–4Cr–4Ti–1.5Y–0.3Ti_3SiC_2	WC–Co	4
8#	-TiC, Si_3N_4, 4hr	V–4Cr–4Ti–1.5Y–0.3TiC	Si_3N_4	4
10#	-TiC, WC, 2hr	V–4Cr–4Ti–1.5Y–0.3TiC	WC–Co	2

Note the "Base" used in 0# means V–4Cr–4Ti matrix only.

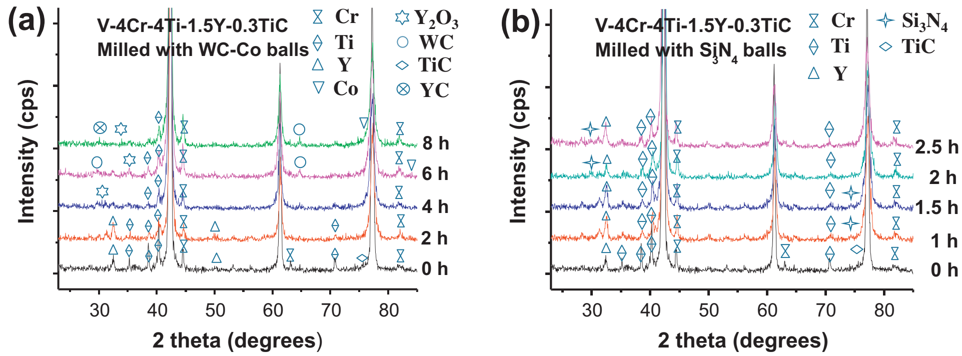

Fig. 1. Typical XRD spectra of V–4Cr–4Ti–1.5Y–0.3TiC during MA with (a) WC–Co balls and (b) Si3N4 balls.

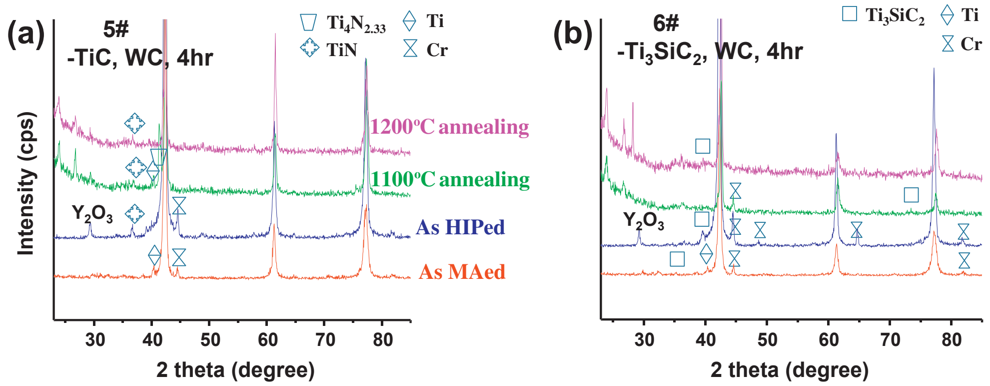

Fig. 2. XRD spectra for (a) TiC and (b) Ti3SiC2 particle-dispersion alloys with all treating procedures.

Table 2
Chemical compositions of particle-dispersed alloys after HIPing.

ID	Chemical compositions (wt%)					
	V	W	Co	Cr	Ti	Y
-SiC, WC, 4hr	Bal.	0.09	<0.02	1.87	3.95	1.43
-TiC, WC, 4hr	Bal.	0.02	<0.02	2.09	4.17	1.48
-Ti_3SiC_2, WC, 4hr	Bal.	<0.02	<0.02	1.22	4.23	1.49
-TiC, Si_3N_4, 4hr	Bal.	–	–	1.35	4.05	1.46
-TiC, WC, 2hr	Bal.	<0.02	<0.02	1.74	4.15	1.43

FRITSCH PULVERISETTE 7 planetary micro mill is used as the MA equipment, with two sets of milling vessels and balls, one set made of WC–Co and the other of Si_3N_4. The ball-to-material weight ratio is 5:1 for both WC–Co and Si_3N_4 milling. The rotation speeds are 340 rpm for WC–Co ball milling and 650 rpm for Si_3N_4 ball milling. The arrangement of the samples is listed in Table 1.

After canning the powders in steel capsules, HIPing is carried out in a 191 MPa argon atmosphere at 1273 K for 3 h. Chemical analysis, annealing at 1373 K and 1473 K for 1 h are carried out on the as-HIPed samples.

During MA, after HIPing and annealing, element distributions are analyzed by scanning electron microscope (SEM) and energy dispersive X-ray (EDX) analysis. Changes in lattice parameter of the V matrix is characterized by X-ray diffraction (XRD). Hardness is measured on the as-HIPed and annealed samples. Size and distribution of nanoparticles are characterized using transmission electron microscope (TEM). Number density of nanoparticles is measured from TEM image under two beam conditions.

3. Results

3.1. Evolution of structure and composition during milling

Fig. 1 shows a typical XRD spectra of V–4Cr–4Ti–1.5Y–0.3TiC during MA with (a) WC–Co balls and (b) Si_3N_4 balls. In this plot, after 4 h of milling with WC–Co, the peaks of the alloying element have mostly disappeared but those of the contaminants such as

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