Abstract

Title: **Super-High Temperature Alloys and Composites from Nb-W-Cr Systems**

Author(s): Shailendra K. Varma
The University of Texas at El Paso
Dept. of Metallurgical & Materials Engr.
500 West University Avenue, M201
El Paso, TX 79968-0520
Work: (915)747-6927
Fax: (915)747-8036
skvarma@utep.edu

Grant Number DE-FG-05NT42491
Performance Period May 2006 through May 2007

Objective: To develop a new material from Nb-W-Cr system for possible applications with temperatures up to 1500^{o}C.

Accomplishments: Ames Laboratory at the Iowa State University fabricated Nb-20W -5Cr (A) and Nb-20W-10Cr (B) alloys by arc melting. All compositions have been expressed in weight percents. The as cast and as received samples had dimensions of ½ x ½ x 1/16 inch slices. The optical microstructural characterization indicates that the higher Cr concentration alloy A is a 2-phase alloy with a matrix containing solid solution of W and Cr in Nb (α) and intermetallic compound ($NbCr_2$) particles. The B alloy is a single phase alloy containing dendritic grains of α only. X-ray mapping in FESEM indicates rather large segregation of Cr around the grain boundaries.

Oxidation experiments have been performed using samples of ¼ x ¼ x 1/16 dimensions in air in a range of temperature from 700 to 1500^{o}C in a computerized temperature controlled furnace. The oxidation experiments were carried out for both 24 and 168 (one week) hours of exposures and weight gain methods were used for obtaining the oxidation curves. It appears that alloy B is much more oxidation resistant at temperatures above 900oC even though extensive powder formation takes place up to almost 1200^{o}C for short term oxidation (STO) experiments up to 24 hours. Complete solid is formed at 1300 and 1400^{o}C while partial melting of the alloy was observed at 1500^{o}C. Long term oxidation (LTO), involving heating up to one week, experiments clearly point to the interesting observation that the alloy B shows improvement in oxidation resistance as a function of temperature.

XRD characterization of the powder formed at 800 and 900^{o}C show the presence of NbO, NbO_2, Nb_2O_5, WO_2, WO_3, Cr_2O_3, and $NbCrO_4$. It must be pointed out that literature indicates that W begins to volatilize at 750^{o}C in the presence of even atmospheric humidity. Due to the simultaneous formation of oxides of various colors the powder coloration is very deceptive. However, complete powder formation at 800, 900 and 1000^{o}C may be attributed to the large relative differences between the linear thermal expansion (LTE) of WO_3, Cr_2O_3 and Nb_2O_5. WO_3 has the LTE values many orders of magnitude higher than that of Cr_2O_3 while Nb_2O_5 has intermediate values.

Improved oxidation resistance with increase in temperature may be attributed to the solubility of oxygen in the metals. It has been found that solubility of oxygen in Nb increases considerably from 1 to 9 atomic percent from 700 to 1915^{o}C while the range is only from 0.0025 to 0.043 atomic percent of oxygen in Cr between 1100 and 1500^{o}C. Extreme interstitial diffusion of oxygen in to rather open BCC structure reduces the formation of Nb_2O_5 and provides more efficient protection from oxidation by Cr_2O_3.

The XPS results for the solids observed at 1200, 1300 and 1400^{o}C indicate the presence of only Cr_2O_3, WO_3, and Nb_2O_5 at the surface. However, XRD results obtained by grinding these bulking solids confirm the presence of these 3 oxides along with $NbCrO_4$ which is believed to be beneficial for the oxidation resistance. Of course, presence of Cr and Nb peaks in such XRD patterns is to be expected while W loss is clearly indicated by the absence of its peak in the pattern. Microstructures after polishing the solids indicate pores and flat areas with varying Cr concentrations.

Names of the Students:

1. Purushotham Raju Kakarlapudi (M.S.)
2. Benedict Portillo (M.S.)
3. Maria D. Gonzalez (Ph.D.)

Conference Presentations:

1. "High Temperature Oxidation of a Nb-W-Cr Alloy in Air Up To 1400^{o}C", Purushotham R. Kakarlapudi, Shailendra Varma, and Ken Natesan, Fifteenth International Symposium on Processing and Fabrication of Advanced Materials (PFAM XV), Materials Science &Technology 2006, Cincinnati, Ohio, October 16, 2006.

2. Oxidation of Nb Based Alloys Between 700 and 1400^{o}C", Shailendra Varma, Purushotham R. Kakarlapudi, Abdul Bhuiya, and Ken Natesan, 210th Electrochemical Society Meeting, High Temperature Corrosion and Materials Chemistry, Cancun, Mexico, October 30, 2006.

3. "Alloys from Nb-W-Cr System for High Temperature Applications", Purushotham R. Kakarlapudi, Shailendra Varma, and Ken Natesan, TMS 2007, 136th Annual Meeting Refractory Metals 2007: Oxidation and Thin Films, Orlando, Florida, February 26, 2007.

4. "Characterization of Oxidation Product in Ternary Alloys Containing C Modfiers", Maria D. Gonzalez, Purushotham Kakarlapudi, Benedict Portillo, and S.K. Varma, Materials Science and Technology 2007, Fundamentals and Characterization: High Temperature Material Systems, Detroit, Michigan, September 2007.

5. "Effect of Boron on High Temperature Oxidation Resistance of Alloys from Nb-W-Cr System", Benedict Portillo, Purushotham Kakarlapudi, and S.K. Varma, Materials Science and Technology 2007, Fundamentals and Characterization: High Temperature Material Systems, Detroit, Michigan, September 2007.

Publications:

1. “High Temperature Oxidation of Nb-20W-10Cr Alloy in Air at up to 1400^{o}C”, Proceedings of Fifteenth International Symposium on Processing and Fabrication of advanced Materials (PFAM XV), Editors: R. Varin and T.S. Srivatsan, Materials Science and Technology (MS&T) 2006, ASM, Warrendale, PA, pp. 131-139, 2006.

2. “Exploration of Nb-W-Cr Alloys for High Temperature Applications in Air”, Benedict Portillo, Purushotham Kakarlapudi, and S.K. Varma, Journal of Metals, Accepted for publication (expected in June 2007 issue).