PROJECT facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Advanced Research

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Super High-Temperature Alloys and Composites From Nb-W-Cr Systems

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Description

The U.S. Department of Energy's Office of Fossil Energy (DOE-FE) has awarded a three-year grant to the University of Texas at El Paso (UTEP) and Argonne National Laboratory (ANL) to jointly explore the high-temperature properties of alloys composed of niobium (Nb), tungsten (W), and chromium (Cr). The grant is administered by the Advanced Research (AR) program of the National Energy Technology Laboratory (NETL) under the Historically Black Colleges and Universities and Other Minority Institutions (HBCU/OMI) program. HBCU/OMI encourages minority participation in fundamental research to develop technologies that promote the efficient and environmentally safe use of coal, oil, and natural gas resources.

Super high-temperature applications involve temperatures in excess of 1,000 °C. There is a critical need for the exploration of new materials for these applications because the nickel (Ni) -based superalloys currently used have reached their upper temperature limit at 1,000 °C. The critical physical and chemical requirements for properties of such materials include: oxidation resistance, high-temperature strength and creep resistance, and low-temperature formability.

Goals

A successful round of research will allow the replacement of Ni-based superalloys with ternary (three-element) alloys that extend the application temperatures to 1,300 °C. The educational aspect of this research includes the involvement of a doctoral graduate student who will complete a dissertation in this area. Every attempt will be made to publish the results in refereed journals and make technical presentations at national and international conferences.

Technical Approach

Ternary alloys from the Nb-W-Cr system have been selected for study in this research. All three metals have body-centered cubic (bcc) crystalline lattice microstructures, making them suitable for high-temperature applications, and have high melting points with the lowest being 1,863 °C for Cr. The density values for Nb, Cr, and W are 8.57, 7.19, and 19.3 g/cm^3, respectively. The alloys Nb-5Cr-20W and Nb-10Cr-20W (all compositions are expressed in weight percents) will be studied in their monolith forms, while composites containing reinforcements of 0.1C, 0.01B, and, 01Y will be tested for potential improvements in:

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PROJECT DURATION

Start Date
08/02/05

End Date
08/30/08

COST

Total Project Value
$386,501

DOE/Non-DOE Share
$200,000 / $186,501

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(a) the formation of metal carbides, (b) toughness, and (c) adhesion of oxide scale to the base alloys, respectively. Variation in Cr concentration in the alloys will establish the influence of solid solutioning, while 10Cr alloys have an additional intermetallic ($NbCr_2$) phase in the microstructure. Second phase particles can introduce resistance to grain growth at elevated temperatures so that retention of high strength at such temperatures may be accomplished.

Effects of solid solutioning, second phase particles, and minor reinforcements will be determined on the oxidation resistance, high-temperature strength and creep resistance (creep strength being the ability to resist strain under constant load over time), and low-temperature formability characteristics of the experimental materials. Oxidation resistance will be determined by the weight gain method. Small buttons of alloys or composites will be heated for two weeks at a time, and weight gain measurements will be made periodically. A graph of weight gain per unit area as a function of oxidation time will provide the oxidation curves at each selected temperature in a range from 500–1,300 °C. Typically, resistance to oxidation increases as temperature increases from 1200-1400 °C, as shown in Figure 1.

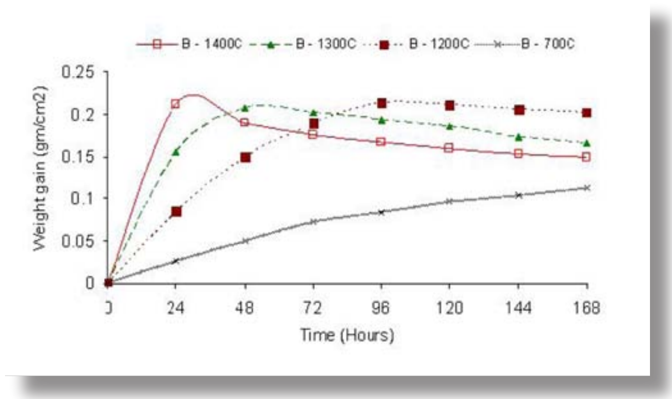

Figure 1. Example of high-temperature metallic oxidation (corrosion) curve

A parabolic equation describing the oxidation curve will be used to determine the energy needed to activate oxidation in the materials being tested, which should provide a basis for comparison with materials from other systems. Mechanisms for oxidation can be delineated by studying the nature of oxide formation with the help of Energy Dispersive X-Ray (EDX) observation on a scanning electron microscope (SEM). Transmission electron microscopy (TEM) will be used to identify the phase and/or the micro constituents present in the scale after an extended period of oxidation. Standard techniques will be used to determine the creep rates, high-temperature tensile strength, and room temperature ductility.

Benefits

This research is expected to contribute to the development of very high-temperature materials suitable for such applications as advanced ultra-supercritical (USC) coal-fired power plants. Such materials are essential for use in construction of coal-fired boilers with advanced steam cycles involving much higher temperatures and pressures than those presently used in conventional pulverized coal (PC) power plants. These higher operating conditions will enable the achievement of much higher efficiencies with the added advantage of reducing emission of carbon dioxide and other effluents as well as solid waste products.