MONOLITHIC Cu-Cr-Nb ALLOYS FOR HIGH TEMPERATURE, HIGH HEAT FLUX APPLICATIONS

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Project Summary

Cu-Cr-Nb alloys have been developed that show exceptional high temperature strength, creep resistance and thermal stability. In addition, they retain most of the thermal and electrical conductivity of pure copper.

Work will focus on completion of the development of the Cu-8 Cr-4 Nb database under the Reusable Launch Vehicle (RLV) NRA 8-21 Task 7.3. The work will concentrate on completion of tensile and creep testing along with associated fractography and quantitative metallography. The results will be combined into a final report and a database that will be transferred to the Rocketdyne Division of Boeing for development of aerospike engine thrust cell liners.

In addition to the database development, work will continue that is focussed on the production of alternatives to the powder metallurgy alloys currently used. Exploration of alternative alloys will be aimed at both the development of lower cost materials and higher performance materials. Another feature of work in this area will be the evaluation of the ductility and strain hardening behavior of candidate alloys under uniaxial and also biaxial loading conditions.

Personnel needed to carry out the listed activities will include 90% of the time of one researcher, Dr. David Ellis, and 10% of the time of one principal researcher, Dr. Ivan Locci. The activities of these two investigators will be based primarily at the NASA Glenn Research Center. Additional work will be accomplished by one faculty member, Gary Michal, in the Department of Materials Science and Engineering at Case Western Reserve University. The bulk of the experimental work will be carried out at the NASA Glenn Research Center to take advantage of both the unique facilities and collaborative opportunities with several of its technical and engineering personnel.

Introduction

Work during the prior four years of this grant has resulted in significant advances in the development of Cu-8 Cr-4 Nb and related Cu-Cr-Nb alloys. The alloys are nearing commercial use in the Reusable Launch Vehicle (RLV) where they are candidate materials for the thrust cell liners of the aerospike engines being developed by Rocketdyne. During the fifth and final year of the grant, it is proposed to complete development of the design level database of mechanical and thermophysical properties and transfer it to NASA Glenn Research Center and Rocketdyne. The database development work will be divided into three main areas: Thermophysical Database Augmentation, Mechanical Testing and Metallography and Fractography.

In addition to the database development, work will continue that is focussed on the production of alternatives to the powder metallurgy alloys currently used. Exploration of alternative alloys will be aimed at both the development of lower cost materials and higher performance materials. A key element of this effort will be the use of Thermo-Calc software to survey the solubility behavior of a wide range of alloying elements in a copper matrix. The ultimate goals would be to define suitable alloy compositions and processing routes to produce thin sheets of the material at either a lower cost, or with improved mechanical and thermal properties compared to the current Cu-Cr-Nb powder metallurgy alloys.

Database Development

Thermophysical Database

Thermophysical testing (thermal expansion, thermal diffusivity, heat capacity and thermal conductivity) has been completed. The results still require analysis and potentially follow-on testing to resolve observed differences in the experimental results from the expected results. Statistical analysis to determine the significant differences will first be done. Where differences exist, additional modeling work will be done to take into account various potential causes for the differences, i.e., compositional effects. When required, additional testing will be conducted to gather supplementary information.

Mechanical Testing

Mechanical testing will focus on three areas; tensile testing, creep testing and low cycle fatigue (LCF) testing.

LCF testing will be conducted by the Structures Division of GRC under NRA 8-21 Task 7.3. However, the investigators will assist with the interpretation and analysis of the results as part of the overall program. Tensile testing will be conducted at room and elevated temperatures to extend the current cryogenic tensile test results to all likely use temperatures. Creep testing will use stresses designed to give creep lives similar to the anticipated lives of thrust cell liners.

Following collection of all the data, the results will be statistically analyzed. Of prime importance for the database development, minimum properties will be established to allow for future design of thrust cell liners.

Metallography and Fractography

Of equal importance with the thermophysical and mechanical properties is the microstructural investigation of the Cu-8 Cr-4 Nb alloy. The work will consist of metallographic examination of the starting powder, as-consolidated material and specimens after testing to observe and quantify the changes in the copper grains and Cr_2Nb precipitates. A combination of optical, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) will be required. The observed changes will be related back to the mechanical and thermophysical properties to quantify the microstructural effects on properties.

Given the high volume fraction of precipitates, the failure mechanism(s) for Cu-8 Cr-4 Nb are anticipated to be substantially different from pure copper and other copper-based alloys. Detailed fractography of selected mechanical testing specimens will be conducted to determine the failure mode and effects of processing, heat treatment and temperature on the failure mode(s).

Alloy Development for Lower Cost and Enhanced Performance

Exploration of alternative alloy compositions will be aimed at both the development of lower cost and higher performance Cu-based alloys. A key element of the effort focussed at higher performance will be the use of Thermo-Calc software to evaluate the solubility behavior of a wide range of alloying elements in a Cu matrix. A goal of that work would be to identify precipitate phases that have very abrupt decreases in solubility with decreasing temperature in FCC-Cu. The work directed at developing lower cost Cu-based alloys with properties comparable to the current powder metallurgy alloys will examine a conventional casting processing route. Alloys will be cast with up to 4 at. pct. Cr and 2 at. pct. Nb. After vacuum induction melting and casting into a Cu mold, the alloys will be solution heat treated, warm rolled and aged. The resulting sheet will be subjected to many of the same tests and test conditions as those that have been applied to the Cu-8 Cr-4 Nb alloy through its database development. This will allow direct comparisons to be made among the various alloys.

In addition to conventional, uniaxial based testing of mechanical properties, an effort will be extended to measure the formability properties of sheet material produced from cast ingots. Newly acquired testing equipment at CWRU will allow assessment of both the biaxial stretching and drawing properties of the sheet. Such tests will evaluate the ductility and strain hardening behavior of the Cu-Cr-Nb alloys under biaxial loading conditions. That information will establish the extent to which the sheet material can be formed by pressing at room temperature into components with various shapes.

Reporting of Results

Reports will be prepared at major milestones in the work as it progresses. It is anticipated that papers from the major areas will be submitted to the appropriate technical forums. Presentations will be given at technical meetings when possible for the coming year. The major document to complete the program will be the final report to NASA Glenn Research Center and Rocketdyne containing the mechanical and thermophysical properties database.

Work With Companies And Other Government Agencies

Based on previous interest of outside companies, it is anticipated that information will be passed directly to manufacturers and other Government agencies interested in the materials. Specifically, work is anticipated to continue with the Rocketdyne Division of Boeing to develop the materials for rocket engine combustion liners. Marshall Space Flight Center has also started development of the processing methods necessary to produce net-shape combustion chamber liners. We anticipate working with them on development and testing of these chambers.