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COPPER AND COPPER ALLOYS FOR FUSION REACTOR APPLICATIONS: SUMMARY REPORT OF A DOE-OFE WORKSHOP*

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The Office of Fusion Energy of the U.S. Department of Energy convened a workshop in April 1983 to review the needs for copper and copper alloys in fusion device applications. The adequacy of the data base on these materials was examined, and recommendations were developed for experimental programs needed to fill identified data gaps. The workshop results are available in a conference proceedings.

Recent analyses of the probable operating requirements of both near-term experimental and longer term power-producing fusion reactors have underscored the need to use copper and copper-base alloys in certain critical applications. These applications can generally be assigned to one of three categories:

- High Heat Flux Components. These include limiter and/or divertor collector plates, beam dumps, direct energy convertors, first walls of high energy density reactors, and protective armor.
- High Thermal/Electrical Conductivity Components. These include rf system components, highly conductive first walls, special sector connectors, and possible diagnostic/instrumentation applications.
- Magnet Components. These applications include leads and stabilizers in superconducting magnets and conductors in various normal magnets where superconductors cannot easily be used due, for example, to maintainability, field requirements, or shielding limitations.

In conceptual and engineering design of these components, fusion designers are often frustrated by the lack of specific property data, particularly for some of the newer, higher strength alloys. Additional complexities are introduced for some applications where operation at elevated temperatures and/or in a neutron radiation environment is required.

A workshop was convened under the auspices of the Office of Fusion Energy, U.S. Department of Energy, to assess and to calibrate the various aspects of the materials and data needs for copper and copper alloys for fusion applications.

Goals of the Workshop were: To provide in-depth descriptions of the requirements presently perceived for copper and copper alloys in fusion applications; to review the known properties, characteristics, and radiation response of commercial and developmental copper alloys; and, to review the objectives and current status of existing fusion-relevant experiments and programs focused on these materials. Presentations were made by representatives of the fusion

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design community, copper and copper alloy manufacturers, and materials specialists from universities, the national laboratories, and industry.

Specific issues which were addressed by the presenters included: temperature limits for copper and copper alloys, temperature-property data (limits of availability), the potential for developing improved alloys, the effects and limitations of welding/brazing operations, the effects of neutron radiation, and currently available product forms and sizes.

The intention of the Workshop was to develop recommendations for the effort needed to assure that qualified copper and copper alloys would be available when they are needed for fusion applications. To this purpose, following presentation of the technical information, Working Groups were convened and charged with developing specific summaries/recommendations in each of the following four areas:

A. Fusion Design Requirements,

B. Status of the Current Data Base,

C. Directions for Alloy Development,

D. Fusion Needs: Experimental Programs.

A brief synopsis of the efforts of each of these Working Groups is presented below.

Fusion Design Requirements

Design requirements were developed for four general areas of application: high heat flux components, rf system components, magnet components, and the first wall. For each application, specific parameter ranges of interest and key (or limiting) materials properties were defined. Finally, a prioritized ranking was developed to express the relative importance of the major thermal, physical, mechanical, and radiation-response properties for each class of components.

Status of the Current Data Base

Attention was given to three segments of the data base available for copper and copper alloys: thermophysical properties, mechanical properties, and manufacturing-related information. In each of these areas the Working Group defined the specific properties of interest, the ranges of important variables (e.g., temperature, magnetic field, joining technology) which are of concern, and provided a listing of possible data sources for each type of property. In addition, specific (albeit qualitative) estimates were provided regarding the perceived adequacy of the data base for each category.

Directions for Alloy Development

This Working Group discussed briefly the metallurgical basis that exists for the potential development and production of high-strength, high-conductivity, high-temperature copper alloys. Separate discussion was offered on each of three types of copper alloys: oxide dispersion-stabilized alloys; low solid solubility, age-hardened alloys containing Cr, Zr, Mg, or similar low solubility alloying elements; and age-hardened alloys such as the Cu-Ti or Cu-Be alloys which undergo coherent aging reactions.

The approximate tensile, stress-rupture, and electrical properties of representatives of each of these alloy groups were compared and additional comments were provided regarding other important characteristics such as joining, fabrication (size) limits, and water corrosion. An outline of a program logic for the development and qualification of copper alloys for fusion reactor applications was provided.

Fusion Needs: Experimental Programs

Consideration of the experimental program needs for fusion applications was separated into needs perceived to be appropriate to near-term (e.g., the present to 1986) and long-term (1987 and beyond) applications. Near-term applications include heat sinks, beam dumps, limiters/divertors, and normal magnet components of interest for such devices as TFTR, MFTF, and the next stage of fusion experimental devices.

Longer term applications would generally parallel those of the short term but would emphasize effects believed or observed to be neutron fluence- or time-dependent. For each time frame of interest, programs associated with irradiation response were considered separate from those where neutron radiation response was not considered important. No attempt was made to specifically prioritize or rank the various program needs.

Summary of Working Group Recommendations

The greatest data void for the application of copper and copper alloys to fusion reactor service is for irradiation effects information. The need is for data over the temperature range 20°C to an upper limit dependent on the properties of each alloy class, perhaps only 300°C for some alloys but well above 450°C for the oxide dispersion-stabilized alloys. The fluence range of interest depends on the application, and ranges from less than 1 dpa to greater than 100 dpa. Irradiation programs must provide adequate simulation of neutron spectrum effects, since solid transmutation products have a strong effect on conductivity. Property measurements that must be included in an irradiation program are electrical, thermal, and mechanical properties.

Future work on copper alloys should use material from a central stock of representative alloys. A possible set of alloys might include:

- Unalloyed copper (e.g., C10100),
- An alloy with Cr, Zr, Mg (e.g., C15000 or AMAX-MZC),
- A Be-Ni alloy (e.g., C17510),
- An oxide-dispersed alloy (e.g., C15715).

Better and more complete characterization of alloy properties is needed, to develop the processing and heat treatments that will optimize specific properties of a given alloy. Should existing alloys prove inadequate for intended applications, alloy development methods exist to optimize compositions within current alloy specification ranges or to develop new copper-base alloys. Possible new systems that indicate promise include Cu-Ti, Cu-Mo, and Cu-V alloys.

The proceedings of this workshop will be published.[1]

REFERENCE

1. F.W. Wiffen and R.E. Gold, editors, Proceedings of the Workshop on Copper and Copper Alloys for Fusion Reactor Applications, CONF-830466 (to be published for the Office of Fusion Energy, U.S. Department of Energy, by Oak Ridge National Laboratory, 1983).