MAB-212A-M

CLEARINGHOUSE
FOR FEDERAL SCIENTIFIC AND
TECHNICAL INFORMATION
Hardcopy | Microfiche
$1.00 | $ .50 | 23 pp
ARCHIVE COPY

AD636180

# SUMMARY REPORT OF THE REFRACTORY METALS SHEET ROLLING PANEL

MATERIALS ADVISORY BOARD

AUG 2 1966

RELEASABLE TO
Clearinghouse for Federal Scientific and Technical Information (CFSTI)

National Academy of Sciences—
National Research Council
Washington, D. C.

# MATERIALS ADVISORY BOARD

## DIVISION OF ENGINEERING

## NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL

### Chairman

Dr. Walter R. Hibbard, Jr. (1966)
Director, Bureau of Mines
Department of Interior
Washington, D. C.

### Members

Professor John C. Bailar, Jr. (1966)
Department of Chemistry & Engineering
The William Albert Noyes Laboratory
The University of Illinois
Urbana, Illinois

Dr. J. H. Crawford (1969)
Assistant Director
Oak Ridge National Laboratory
Solid State Division
Oak Ridge, Tennessee

Mr. George C. Deutsch, Chief (1966)
Materials Research Program
National Aeronautics & Space Admin.
Washington, D. C. 20546

Dr. Morris E. Fine (1967)
Associate Chairman
Office of the Chairman
Materials Research Center
Northwestern University
Evanston, Illinois

Dr. Walter L. Finlay (1967)
Assistant Vice Pres.—Research
Copper Range Co.
630 Fifth Avenue
New York, N. Y. 10020

Dr. Wayne E. Hall (1966)
Assistant Chief Geologist
Experimental Geology
U.S. Geological Survey
Washington 25, D. C.

Dr. N. Bruce Hannay (1969)
Chemical Director
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey 07971

Mr. J. Harry Jackson (1968)
General Director
Metallurgical Research Division
Reynolds Metals Company
Fourth and Canal Streets
Richmond 19, Virginia

Mr. Humboldt W. Leverenz (1968)
Associate Director
RCA Laboratories
David Sarnoff Research Center
Princeton, New Jersey

Mr. Alan Levy (1967)
Manager, Materials & Fabrication
Research and Development Department
Solid Rocket Operations
Aerojet-General Corporation
Sacramento, California

Dr. D. J. McPherson (1967)
Vice President
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Dr. M. Eugene Merchant (1966)
Director of Physical Research
Cincinnati Milling Machine Company
Cincinnati 9, Ohio

Dr. E. F. Osborn (1969)
Vice President for Research
The Pennsylvania State University
University Park, Pennsylvania

Dr. Joseph A. Pask (1968)
Department of Mineral Technology
University of California
Berkeley 4, California

Dr. Malcolm M. Renfrew, Head (1967)
Department of Physical Sciences
University of Idaho
Moscow, Idaho

Dr. Preston Robinson (1966)
Director-Consultant
Sprague Electric Company
North Adams, Massachusetts

Mr. Adolph O. Schaefer (1969)
Consulting Engineer
R. D. 4
Norristown, Pennsylvania

Dr. Irl C. Schoonover (1966)
Deputy Director
National Bureau of Standards
Washington 25, D. C.

Dean Robert D. Stout (1968)
Graduate School
Lehigh University
Bethlehem, Pennsylvania

Dr. Morris Tanenbaum (1969)
Director of Research and Development
Western Electric Company
P. O. Box 900
Princeton, New Jersey 08540

Mr. Alfred C. Webber (1968)
Research Associate
Plastics Department
Experimental Station
Building 323, Room 210
E. I. duPont de Nemours & Co., Inc.
Wilmington, Delaware 19898

Mr. F. Travers Wood, Jr. (1968)
Director
Engineering Laboratories & Services
Missile & Space Systems Division
Douglas Aircraft Company, Inc.
Santa Monica, California

**THE NATIONAL ACADEMY OF SCIENCES** is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, alhough the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

**THE NATIONAL ACADEMY OF ENGINEERING** was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineerng and share the responsbility of advising the Federal Government, upon request, on any subject of science or technology.

**THE NATIONAL RESEARCH COUNCIL** was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and egnineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

**THE DIVISION OF ENGINEERING** is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

**THE MATERIALS ADVISORY BOARD** is a unit of the Division of Engineering of the National Academy of Sciences-National Research Council. It was organized in 1951 under the name of the Metallurgical Advisory Board to provide to the Academy advisory services and studies in the broad field of metallurgical science and technology. Since the organization date, the scope has been expanded to include organic and inorganic nonmetallic materials, and the name has been changed to the Materials Advisory Board.

Under a contract between the Office of the Secretary of Defense and the National Academy of Sciences, the Board's present assignment is

> "...to conduct studies, surveys, make critical analyses. and prepare and furnish to the Director of Defense Research and Engineering advisory and technical reports, with respect to the entire field of materials research, including the planning phases thereof."

# SUMMARY REPORT

of the

# REFRACTORY METALS SHEET ROLLING PANEL

Prepared By The

MATERIALS ADVISORY BOARD

Division of Engineering
National Research Council

as a service of

The National Academy of Sciences

to the

Office of Defense Research and Engineering
Department of Defense

RELEASABLE TO

Clearinghouse for Federal Scientific and Technical Information (CFSTI)

Publication MAB-212A-M
National Academy of Sciences-National Research Council
Washington, D. C.
June 1966

The Academy and its Research Council perform study, evaluation, or advisory functions through groups composed of individuals selected from academic, Governmental, and industrial sources for their competence or interest in the subject under consideration. The members serve as individuals contributing their personal knowledge and judgments and not as representatives of their parent organization.

This report completes a study undertaken by the Materials Advisory Board for the National Academy of Sciences in execution of work under Defense Supply Service Contract No. DA-49-083 OSA 313 between the Department of Defense and the National Academy of Sciences.

No portion of this report may be published without prior approval of the contracting agency.

# ROSTER

## MATERIALS ADVISORY BOARD

## REFRACTORY METALS SHEET ROLLING PANEL

Chairman: Mr. G. Mervin Ault, Associate Chief
Materials & Structure Division
Lewis Research Center, NASA
21000 Brookpark Road
Cleveland, Ohio 44135

### Members

Mr. David C. Goldberg, Manager
Structural Materials & Processes
Astronuclear Laboratory
Westinghouse Electric Corporation
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

Dr. Robert I. Jaffee
Senior Fellow
Department of Physics
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio

Mr. Alan V. Levy, Manager
Materials & Fabrication
Research & Development Department
Solid Rocket Operation
Aerojet General Corporation
Sacramento, California

Mr. Roger Perkins
Staff Scientist
Materials Sciences Laboratory
Lockheed Missiles & Space Company
Palo Alto, California

Mr. L. M. Raring, Manager
Research & Development
Fansteel Metallurgical Corp.
Number One Tantalum Place
North Chicago, Illinois

Professor Leslie L. Seigle
State University of New York
Department of Material Sciences
College of Engineering
Stony Brook, Long Island
New York

Mr. Howard Siegel
Senior Technical Specialist
Material & Process Department
McDonnell Aircraft Corporation
St. Louis, Missouri

Mr. John T. Stacy
Senior Group Engineer
The Boeing Company
Aero-Space Division
P. O. Box 3707
Seattle 24, Washington

## Liaison Representatives

DOD Mr. John Barrett, Office of the Director of Defense, Research and Engineering, The Pentagon, Washington, D. C. 20301

AF Mr. J. K. Elbaum, Code MAMP, Physical Metallurgy Branch, Materials and Ceramics Division, Materials Laboratory, Wright-Patterson Air Force Base, Ohio

Mr. George Glenn, Code MATB, Wright-Patterson Air Force Base, Ohio

Mr. I. Perlmutter, Code MAMP, Chief, Physical Metallurgy Branch Materials and Ceramics Division, Materials Laboratory, Wright-Patterson Air Force Base, Ohio

Army Mr. S. V. Arnold, Army Materials Research Agency, Watertown Arsenal Watertown, Massachusetts

Navy Mr. I. Machlin, Materials Division, Code RRMA-23, Naval Air Systems Command, Department of the Navy, Washington, D. C. 20360

Mr. N. E. Promisel, Chief Materials Engineer, Code RRMA, Naval Air Systems Command, Department of the Navy, Washington, D. C. 20360

AEC Mr. Andrew Van Echo, Reactor Development Division, Atomic Energy Commission, Washington, D. C. 20545

NASA Mr. J. Maltz, Materials Research Program, Code RRM, National Aeronautics & Space Administration, Washington, D. C. 20546

MAB Staff: Dr. Joseph R. Lane
Staff Metallurgist
Materials Advisory Board
National Academy of Sciences-
National Research Council
2101 Constitution Avenue
Washington, D. C. 20418

Former Members & Liaison Representatives

T. D. Cooper, Air Force
E. Czarnecki, Boeing
S. Christopher, AEC
J. Simmons, AEC
J. Maltz, Navy
L. P. Jahnke, G.E.
W. Rostoker, Univ. of Ill.
A. L. Rustay, Wyman-Gordon
G. Timmons, Climax Molybdenum

Participating Members of the Subpanels:

Alloy Requirements & Selection

Dr. Robert I. Jaffee, Battelle Memorial Institute (Chairman)
Mr. G. Mervin Ault, Lewis Research Center, NASA
Mr. Alan V. Levy, Aerojet-General Corporation

Former Member

Mr. L. Jahnke, General Electric Company

Analysis Methods

Prof. L. L. Seigle, State Univ. of New York, Stony Brook (Co-Chairman)
Mr. Theodore D. McKinley, duPont & Company (Co-Chairman)
Dr. James R. DeVoe, National Bureau of Standards
Dr. Velmer A. Fassel, Iowa State University
Mr. William F. Harris, Youngstown Sheet & Tube Company
Dr. Manley W. Mallett, General Electric Company

Former Member

Mr. B. F. Scribner, National Bureau of Standards

Coating

Mr. James J. Gangler, National Aeronautics & Space Admin. (Chairman)
Dr. C. A. Krier, Boeing Company
Mr. Donald Kummer, McDonnell Aircraft Corporation
Mr. Harry A. Pearl, Naval Underwater Ordnance Laboratory
Dr. David K. Priest, Fansteel Metallurgical Corporation

Former Members

Mr. M. Kushner, Boeing Company
Mr. A. V. Levy, Aerojet-General Corporation
Mr. D. Cona, Boeing Company
Dr. R. I. Jaffee, Battelle Memorial Institute
Mr. E. D. Sayre, General Electric Company

Consolidation and Processing

Dr. William Rostoker, University of Illinois (Chairman)
Dr. W. A. Backofen, Massachusetts Institute of Technology
Mr. R. A. Beall, Bureau of Mines
Professor Morris E. Fine, Northwestern University
Dr. H. H. Hausner, Consulting Metallurgist
Professor N. H. Polakowski, Illinois Institute of Technology

Ad Hoc Infab

Mr. David Goldberg, Westinghouse Electric Corporation (Chairman)
Dr. Robert I. Jaffee, Battelle Memorial Institute
Dr. James Wong, National Research Corporation

Former Members

Dr. William Rostoker, University of Illinois
Mr. L. P. Jahnke, General Electric Company

Joining

Dr. William Rostoker, University of Illinois (Chairman)
Mr. Alan F. Busto, Fansteel Metallurgical Corporation
Mr. William N. Platte, Westinghouse Electric Corporation
Mr. Harry Schwartzbart, IIT Research Institute

Phase II

Mr. G. M. Ault, Lewis Research Center, NASA (Chairman)
Dr. Robert I. Jaffee, Battelle Memorial Institute
Mr. L. P. Jahnke, General Electric Company
Mr. Alan V. Levy, Aerojet-General Corporation
Mr. John T. Stacy, Boeing Company

Phase III

Mr. Roger Perkins, Lockheed Missiles & Space Company (Chairman)
Mr. Donald A. Honebrink, Boeing Company
Mr. Howard Siegel, McDonnell Aircraft Corporation
Mr. Edward D. Weisert, Rocketdyne Division of N.A.A.
Dr. James Wong, National Research Corporation

Quality Specifications

Mr. John T. Stacy, Boeing Company (Chairman)
Mr. S. Bramer, Douglas Aircraft Corporation
Mr. Robert Freeman, Climax Molybdenum Company of Michigan
Mr. Basil T. Lanphier, Carpenter Steel Company

Former Members

Mr. Arnold Rustay, Wyman-Gordon
Mr. George Timmons, Climax Molybdenum Company of Michigan

Standardization of Test Methods

Mr. L. M. Raring, Fansteel Metallurgical Corporation (Chairman)
Mr. Donald A. Douglas, Jr., Oak Ridge National Laboratory
Mr. Michael J. Manjoine, Westinghouse Electric Corporation
Mr. Roger Perkins, Lockheed Missiles & Space Company

Steering

Mr. G. Mervin Ault, Lewis Research Center, NASA (Chairman)
Dr. Robert I. Jaffee, Battelle Memorial Institute

Former Member

Mr. L. P. Jahnke, General Electric Company

Tubing

Mr. William Thurber, Union Carbide Corporation (Chairman)
Mr. David C. Goldberg, Westinghouse Electric Corporation
Dr. Robert I. Jaffee, Battelle Memorial Institute
Mr. L. M. Raring, Fansteel Metallurgical Corporation
Mr. John T. Stacy, Boeing Company

CONTENTS

| | Page |
|---|---|
| Introduction | 1 |
| Need | 1 |
| Method of Operation | 2 |
| Alloy Selection | 3 |
| Program Conduct Through the Three Phases | 4 |
| General Program Achievements | 5 |
| Auxiliary Subpanel Activities | 6 |
| Concluding Remarks | 6 |
| Recommendations | 7 |
| References | 8 |

SUMMARY REPORT

REFRACTORY METALS SHEET ROLLING PANEL

## Introduction

The Materials Advisory Board Refractory Metals Sheet Rolling Program was originally established at the request of the Department of the Navy, Bureau of Naval Weapons, to identify causes responsible for variation in refractory metal sheet and to develop remedies for these difficulties. It was intended, in general, to develop a comprehensive technology for making high-quality, reproducible, widely usable material, with all the implications therein, responsive to the established requirements of weapons and vehicle designers. The program subsequently was expanded through the Department of Defense to include the other Services, NASA, and AEC in a broadly based, integrated effort.

At this writing, six years later, the refractory metal sheet industry in the United States is a going business. In the last few years, there has been available a choice of strong alloys, wide and thin sheet (to 36" wide, and in narrower widths, down to foil gages) produced to close tolerances, a background of property data and formability experience, and finally, sufficient production know-how to permit reasonable deliveries and realistic quotations. Several of the currently available alloys were unknown at the start of the program. It is believed that the coordinated sheet rolling program under the guidance of the Refractory Metals Sheet Rolling Panel and its eleven Subpanels has made a significant contribution to this progress.

It is the purpose of this document to summarize the modus operandi, the accomplishments of the program, and finally, recommendations of the Panel for completion of the present program and continuation of related development activities. A more detailed summary of the main Panel and Subpanel activities and recommendations may be found in the Final Report of the Refractory Metals Sheet Rolling Panel (ref. 1), and a summary of contractor technical achievements will be found in a report prepared by the Defense Metals Information Center (ref. 2). Reference 3 summarizes the Subpanel reports which have been issued. It is hoped that this present document will entice the interested reader into a more detailed study of those references.

## Need

At the inception there was a need for refractory metal sheet for certain research and development vehicles or devices such as the X-20 hypersonic glider, ramjets, and solid rocket components plus, certainly,

the knowledge that with the constantly upward trend in operating temperatures, requirements would be present if quality sheet of the proper alloys could be provided.

The recently completed studies of the MAB Aerospace Applications Requirements Panel (ref. 4) outlined requirements for all materials for propulsion systems (turbojet, turborocket, turboramjet, ramjet, liquid rocket, solid rocket, and electrical propulsion) and vehicle systems intended for operational capability in 1970. They reviewed devices, components, operational and environmental regime of components, and looked at fabrication requirements. For the propulsion systems alone, they specified four sheet and plate requirements, three tubing requirements, three forging requirements, four coating requirements, and two thermionic device requirements for refractory metals. In reviewing fabrication requirements, it was found that 18 of 44 were due to the use of refractory metals. It was concluded that refractory metals will be a pacing item. The report broke down the problems of priority and identified seven items on refractory metals in priority I.

At the start of the program, very few refractory metal alloys were available, surface and dimensional control was poor, and worst of all, product quality was extremely variable. This was the era when unalloyed molybdenum was beginning to be replaced by the Mo-0.5Ti alloy, Cb-1Zr was the columbium alloy, there were no tantalum alloys, and no sizeable tungsten sheet.

A major quality problem in the limited compositions available was lack of uniformity. Variable formability and tendency to delaminate or crack during shearing and forming were persistent problems in attempted applications. These problems were most pronounced with Mo- and W-based materials. All of the refractory metals considered in this program, W, Ta, Mo, and Cb, are body-centered cubic metals and at least W, Mo, and Cb exhibit a ductile-brittle transition temperature. It is desired that this DBTT be below room temperature to facilitate handling and forming. Molybdenum sheet was found to have an extremely variable DBTT, usually above room temperature.

Surface contamination was another persistent problem. Columbium and tantalum alloys are particularly prone to contamination from oxygen and nitrogen when heated, and some molybdenum alloys are also susceptible. Such contamination reduced bend ductility and formability. The lack of uniformity also affected mechanical properties, and as a result many designers felt that refractory metals were not ready to be specified.

## Method of Operation

The Panel decided that the program should be divided into three phases for each alloy:

Phase I - Development and documentation of a production practice for high-quality sheet and production of a quantity of sheet to demonstrate and establish quality and uniformity.

Phase II - Measurement of preliminary design data for the "pedigreed" sheet from Phase I.

Phase III - Establishment of limits of formability and definition of forming and joining procedures for sheet, followed by tests of fabricated structural elements. In some cases prototype aerospace vehicle or propulsion system components were to be designed, fabricated, and evaluated.

## Alloy Selection

Of major importance was the decision as to which refractory metals or alloys should be fed into the program. This portion of the activity was the responsibility of the Subpanel on Alloy Requirements and Selection. This group has repeatedly surveyed the requirements for these materials by consulting the consumers and by referring to the product of the Aerospace Applications Requirements Panel of the Materials Advisory Board (ref. 4). They conducted, at the initiation of the program, a survey to learn the status of refractory metal alloy development in this country. Based upon these surveys, they decided it was desirable to set target properties for six specific classes of alloys:

1. Fabricable molybdenum
2. High-strength molybdenum
3. Fabricable high-strength columbium (originally separated into two classes)
4. Tantalum
5. Unalloyed or dilute tungsten
6. High-strength tungsten

The targets served two purposes: (1) they provided the industry with specific objectives permitting them to focus their efforts for alloy development, (2) they comprised specific tests for which data that should be obtained to permit valid comparisons to be made. The stimulus for response by the industry was the opportunity for Panel endorsement and thus for Government support for Phases I, II, and III for the selected alloys.

The targets were submitted to the industry and a date for review of a particular alloy class (e.g., high-strength fabricable columbium alloys) was announced. On the selected date all organizations offering candidate

alloys were given time to present to the Subpanel the fabrication history, experience, and properties for their candidate. In closed session, the Subpanel compared the candidates and made their selections. Copies of the minutes of this meeting, including Subpanel recommendations, were sent to all participants and to the main Panel and Government contractors for action. (The documented history of these meetings and recommendations may be found in ref. 1.) By this process, a large number of candidates were narrowed down to a very few that most nearly met the targets. The selective focusing upon a very few alloys by an impartial body is considered to be a very important feature of such a development scale-up program, and especially important when the potential market is small, the need great, and the cost of the final product in 0.040-inch sheet is in the range of $30 to $280 per square foot.

Alloy selection has been an intensive process spanning several years. It required an estimation of future (and unknown) requirements, a knowledge of present capabilities, and a need to balance producibility against high properties. Those involved in the program were impressed with the manner in which industry responded to the challenge. Once clear objectives had been established, producers, whether under contract or not, made rapid progress so that within a few years several alloys in each class were available for selection. It is significant to note that at this date the target properties have been achieved for all classes except high-strength molybdenum.

Program Conduct Through the Three Phases

As will be appreciated, it is a long road from a laboratory sample to commercial availability of large sheet with good surface and flatness and close tolerances and reproducible properties. Largely, Phase I of the Refractory Metal Sheet Rolling Program was concerned with this aspect of the overall development of an alloy into a usable engineering material. During scale-up, the composition may change, mechanical properties do not always hold up, segregation is often a problem, and other, similar problems occur. Nevertheless, in this period, we have seen the process development accomplished for alloys of molybdenum, columbium, and unalloyed tungsten, with tantalum alloys not far behind.

Following completion of Phase I, several of the alloys were recommended for additional contract programming through Phases II and III. The contractors regularly documented their progress and DMIC has issued a series of reports describing contractor achievements. A report summarizing all contractor progress to date will be released by DMIC in mid-1966. This report itemizes quantity of material produced, and records processing development, properties achieved, and quality (in terms of flatness, gage control, etc.) for Phase I contracts; more complete property evaluation by Phase II contractors; and fabricability as determined by Phase II contractors.

## General Program Achievements

To highlight the progress under the program, we may compare in Table 1 the current status of the alloys for high-quality sheet with their status when the program began in November 1959. This Table shows that several of the alloys which have advanced within the time period of the program to a point where sheet can be produced in large sizes with good quality and uniformity were unknown at the start of the program. The program results in terms of material quality (flatness, gage control, and reproducibility) are summarized in refs. 1 and 2.

Most important, the effort was focused. Only a few carefully chosen alloys were selected for development; only a limited number of the most important properties were measured, but in a way to permit needed comparisons, and a real effort was made to avoid unknown or unneeded duplication. Certainly the Government saved much money and time because of this selectivity and coordination. As a result there now exists a production base that can turn out a quality product. This was the prime objective of the program.

It would be difficult to say with conviction that the job is finished. The major objectives have been met but the Panel has recommended a modified Phase I and Phase II activity for several materials (see Table 2) that remain to be implemented. The Panel has recommended that specific responsibility be assigned for collection and dissemination of such production and property information beyond the formal lifetime of the Panel.

In Table 2, the Panel has not recommended further work in high-strength tungsten and molybdenum. This is because requirements were not specific enough to justify production development at this time. The AARP report, however, suggests that such material will be a firm requirement soon.

Ductile high-strength tungsten alloys containing about 5 per cent rhenium have been reviewed by the Alloy Requirements and Selection Subpanel. It was recommended that additional laboratory optimization be conducted, and that a selected alloy or alloys be scaled up at least to the pilot level for demonstration of feasibility and determination of property data.

The Panel clearly saw an immediate need for refractory metal tubing of the same alloys of columbium and tantalum endorsed in the sheet program. This coordinated activity should continue--the preferred method is to continue the Tubing Subpanel.

It is important that the alloys in sheet configuration be formable and that the formability be documented. The results of the Phase III studies that are determining the formability limits demonstrate that the alloys of the program are considerably superior to material available before the initiation of the program. (Details may be found in refs. 1 and 2.)

## Auxiliary Subpanel Activities

A particularly important contribution of the Panel activity has been the output of the subpanels. During the tenure of the main Panel, eleven subpanels were created to aid in guidance, to provide standards, or to survey the state of the art and recommend needed research.

The Test Methods Subpanel has provided guidelines for testing or refractory metals where none existed before. The Coating Subpanel similarly provided needed recommendations for standard tests for coated refractory metals. The Quality Specifications Subpanel has provided targets for refractory metal sheet quality and outlined sheet sampling methods. All are being widely used. The Analysis Methods Subpanel has guided round robins for measurement of capability of analysis methods in refractory metal alloys. Several of the panels have recommended needed research that has been supported by the Services. Detailed summaries of the subpanel activities will be found in ref. 1.

Preceding discussions of contractor progress at meetings of the Panel, a DMIC representative summarized critical points.

## Concluding Remarks

The Refractory Metals Sheet Rolling Panel nominally has been a coordinated effort to achieve high-quality refractory metal alloys in one product form, flat sheet. Because these same alloys are of interest for forging and tubing forms and because consolidation and ingot breakdown studied for sheet are prerequisites of all wrought forms, it can be said there has been considerable spin-off that has aided these other product forms.

The accomplishments were results of coordination among the military, the consumers, the fabricators, and the metal producers who became acquainted with each other's problems. Requirements were well publicized. The Services, NASA, and the AEC cooperated with each other to a high degree.

The general format used (originally developed for the Titanium Sheet Rolling Program) is deemed to be sound and important to success. This format consists of (1) setting targets for alloy selection based upon a consideration of requirements and potential capability; (2) selection of alloys, from all candidates offered, for scale-up development; (3) providing technical guidance for the three phases (development of production capability, design data, and evaluation of fabricability), and (4) continuous review of contracted programs to insure compliance with objectives. (Some criticisms of the details of the approach will be found in ref. 1.)

Coatings of the refractory metals are the key to successful application of refractory metals in many propulsion and vehicle systems. The

Coating Subpanel has established testing standards and evaluated specific coatings in several temperature-time spectrums. A coordinated approach in this area has been a major need for years. It is recommended that this activity continue.

Major benefits were derived by the focusing upon objectives, by narrowing the list of alloys whose development should be supported, by getting people together to define and attack common problems. In an area such as high-strength refractory metals, where the costs of the product and of development are high, the market small, and where the Government in the end is the major consumer, it seems imperative that the production industry and the consumer continue to get together in some working forum to provide mutual guidance. Some have proposed that whereas the Sheet Rolling Panel has concerned itself with bringing along process development of the required sheet, the future activity should concern itself with all product forms in refractory metals. If a "working forum" concept for future activities in refractory metals can be developed, a forum where less time-consuming concer with contractor problems will occur, more attention can be paid to selected applied materials research and process development.

The Panel has recommended that a "working forum" or a standing "Refractory Metals Requirements and Selection Panel" be created to review regularly and inform among the Government, consumer, producer, and R&D groups, in the area of refractory metal developments leading to all needed product forms. The "minutes" of such meetings should be available to all to provide maximum information for guidance of both industry in-house and Government programs. It has been proved that proper action will follow if objectives can be clarified and made known to those who must respond. It is deemed an essential feature of such activity that an "Alloy Selection Group" would impartially select specific compositions to recommend for Government support for process developments. Costs are too great and market too small to permit the luxury of process development of a large variety of compositions for a specific product form. The Panel suggests that this approach may, indeed, be appropriate for a wide variety of materials required in Government programs, particularly where there is critical need and a small market.

## Recommendations

The Panel respectfully proposes the following:

1. Complete the current program, i.e., a modified Phase I and Phase II activity for several materials. For detailed comments see ref. 1.

2. Continue coordinated coating program.

3. Continue coordinated tubing program.

4. Create "working forum" or a standing "Refractory Metals Requirements and Selection Panel" (RMRSP) to review regularly and inform, among the Government, consumer, producer, and R&D groups, in the area of refractory metal developments leading to all needed product forms.

Additional recommendations will be found in the specific subpanel summaries, ref. 1.

## References


1. "Final Report of the Refractory Metals Sheet Rolling Panel" MAB-212-M Materials Advisory Board, National Academy of Sciences-National Research Council, February 1966.

2. "Summary of Contractor Results in Support of the Refractory Metals Sheet Rolling Program", Defense Metals Information Center Report No. 231 to be issued in 1966.

3. "Joining of Refractory Sheet Metals" MAB-171-M, March 20, 1961
"Report of the Subpanel on Analytical Techniques, Refractory Metals Sheet Rolling Program" MAB-178-M, November 15, 1961
"Report of the Subpanel on Consolidation and Fabrication, Refractory Metals Sheet Rolling Program" MAB-179-M, November 1, 1961
"Report of the Subpanel on Coatings, Refractory Metals Sheet Rolling Panel" MAB-181-M, June 1, 1962
"Report of the Subpanel on Quality Specifications, Refractory Metals Sheet Rolling Panel" MAB-184-M, June 8, 1962
"Evaluation Procedures for Screening Coated Refractory Metal Sheet" MAB-189-M, February 15, 1963
"Quality Sampling Specification for Tungsten Plate" MAB-190-M March 15, 1963
"Recommended Quality Standards for Tungsten Sheet Produced in the Refractory Metals Sheet Rolling Program" MAB-196-M, January 22, 1964
"Procedures for Evaluating Coated Refractory Metal Sheet" MAB-201-M August 10, 1964
"Status of Refractory Alloy Tubing - 1964" MAB-208-M, August 18, 1965
"Coating Technology - 1965, Oxidation-Resistant Coatings for Refractory Metals" MAB-210-M, November 1965
"Evaluation Test Methods for Refractory Metal Sheet Material" MAB-216-M, November 1965
"Cooperative Analysis Program on Refractory Metal Alloys" MAB-217-M February 1966
"Processing of Materials in INFAB" MAB-99-LM, March 20, 1963
"Final Report of the Ad Hoc Infab Subpanel, Refractory Metals Sheet Rolling Panel" MAB-100-LM, March 26, 1965
All published by the Materials Advisory Board, National Academy of Sciences-National Research Council.

4. "Design Requirements" (U) Vol. 2 of 4 (Classified) MAB-200-M(AAR-2) Report of Aerospace Applications Requirements Panel, Materials Advisory Board, National Academy of Sciences-National Research Council September 1965.

Table 1

History of Alloys Identified for Production Development by Sheet Rolling Panel

| Alloy Class | Status November 1959 | Status - 1965 |
|---|---|---|
| **Fabricable molybdenum** | | |
| Mo-1/2Ti | Large sheet poor quality | Completed production program (24 x 72" sheet) |
| TZM (Mo-0.5Ti-0.1Zr-0.03C) | Small sheet | Completed production program (24 x 72" sheet) |
| **Tungsten** | | |
| Unalloyed | Lab. size sheet | Completed production program (18 x 48" sheet) |
| **Fabricable & weldable columbium** | | |
| D-43 (Cb-10W-1Zr-0.1C) | Unknown | Completed production program (24" wide) |
| Cb-752 (Cb-10W-2.5Zr) | Unknown | Completed production program (24" wide) |
| FS-85 (Cb-28Ta-10W-1Zr) | Unknown | Completed pilot production (18" wide) |
| **Tantalum** | | |
| T-222 (Ta-10W-2.5Zr-0.01C) | Unknown | Completed pilot production |
| GE-473 (Ta-7W-3Re)[a] | Unknown | Completed pilot production |

[a] Development funded by G. E.

## Table 2

### Panel Recommendations in Current Program

| Alloy | Phase I (Production) | Phase II (Prelim. Design Data) | Phase III (Fabrication) |
|---|---|---|---|
| **Fab. Mo** | | | |
| 1/2%Ti | Universal Cyclops | Southern Research | McDonnell |
| TZM | Universal Cyclops | Southern Research | McDonnell |
| **Unalloyed W** | | | |
| P.M. | Fansteel | Southern Research | Solar |
| Arc Cast | Universal Cyclops | Not Recommended | Super-Temp |
| **Tantalum** | | | |
| 30Cb-7½V | Wah Chang | Not Recommended | ---------- |
| T-222 | Not Recommended | Recommended[a] | Not Recommended |
| GE-473 | Not Recommended | Recommended[a] | Not Recommended |
| **Columbium** | | | |
| D-43 | du Pont | Recommended[b] | Not Recommended |
| Cb-752 | Haynes (pilot) | Recommended[b] | Not Recommended |
| FS-85 | Recommended | Recommended[b] | Not Recommended |
| **High Strength Mo** | | | |
| Arc Cast TZC[c] | ---------- | ---------- | ---------- |
| Powder Met. TZM[c] | ---------- | ---------- | ---------- |
| **Ductile W[d]** | ---------- | ---------- | ---------- |
| **High Strength W[d]** | ---------- | ---------- | ---------- |

Table 2 (continued)

Notes

(a) Recommended Phase I production (not necessarily process development) of sufficient quantity of material to fix and define the production process and to provide material for Phase II evaluation of this pedigreed material.

(b) Recommended collection and assembly of Phase II data (and Phase III where possible) of material already produced in Phase I.

(c) Identified as candidate for preproduction program when requirements for high-strength molybdenum warrent.

(d) Alloys were identified that have exceptional promise. After additional laboratory optimization has been completed, at least a pilot study is recommended. (See MAB-212-M, p. 120)

Unclassified

Security Classification

**DOCUMENT CONTROL DATA - R&D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>National Academy of Sciences-National Research Council<br>Washington, D. C. 20418 | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP |

3. REPORT TITLE

SUMMARY REPORT OF THE REFRACTORY METALS SHEET ROLLING PANEL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Summary Report of a Final Report June 1959 - December 1965

5. AUTHOR(S) (Last name, first name, initial)

Materials Advisory Board Refractory Metals Sheet Rolling Panel

| | | |
|---|---|---|
| 6. REPORT DATE<br>June 1966 | 7a. TOTAL NO. OF PAGES<br>19 | 7b. NO. OF REFS<br>18 |
| 8a. CONTRACT OR GRANT NO.<br>DA-49-083 OSA 313 Defense Supply Service<br>b. PROJECT NO<br>c<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>MAB-212A-M<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) | |

10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Assistant Director (Materials)<br>ODDR&E, The Pentagon, Washington, D. C. |

13. ABSTRACT

The method of operation, accomplishments and recommendations of the Panel are outlined (summarizing the contents of MAB-212-M, "Final Report of the Refractory Metals Sheet Rolling Panel").

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

| 14 KEY WORDS | LINK A ROLE | LINK A WT | LINK B ROLE | LINK B WT | LINK C ROLE | LINK C WT |
|---|---|---|---|---|---|---|
| Refractory metals | | | | | | |
| Molybdenum alloys | | | | | | |
| Columbium alloys | | | | | | |
| Tantalum alloys | | | | | | |
| Tungsten alloys | | | | | | |
| Mechanical properties | | | | | | |
| Chemical analysis | | | | | | |
| Test methods | | | | | | |
| Oxidation-resistant coatings | | | | | | |
| Tubing | | | | | | |
| Quality specifications | | | | | | |
| Alloy selection | | | | | | |

## INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

DD FORM 1 JAN 64 1473 (BACK)

Unclassified

Security Classification