NOVEMBER, 1961

DEFENSE METALS INFORMATION CENTER

SELECTED ACCESSIONS

BATTELLE MEMORIAL INSTITUTE
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November 1961

HIGH-STRENGTH ALLOYS

44206 A SUMMARY OF THE THEORY OF FRACTURE IN METALS. J. W. Spretnak, Battelle Memorial Institute, Columbus, Ohio. DMIC Report 157, August 7, 1961
(51 references, 64 pages, 18 figures, 3 tables)

The theoretical strength of metals, based on atomic forces, is in the order of 100 to 1000 greater than that observed. The various reasons for this discrepancy between theoretical and observed strength are discussed in detail, but the more important ones are (1) lattice imperfections, (2) the fact that real metals are polycrystalline aggregates, (3) crystalline anisotropy, and (4) the ability of metals to deform by shear.

Plastic flow, particularly heterogeneous plastic flow, is intimately associated with crack initiation. The precise conditions under which plastic flow ceases and bond rupturing (cracking) begins are not completely understood. The body-centered cubic lattice has geometric characteristics that make it particularly susceptible to fracture with little or no preceding plastic flow. Multidirectional stress fields, both microscopic and macroscopic, affect the degree of plastic deformation that precedes crack initiation. The theory of fracture as it exists today is reviewed. Though incomplete in many respects, it can be helpful in understanding the behavior of metal structures.

44214 MATERIALS SYMPOSIUM. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. TR 61-322, Materials Symposium, Phoenix, Arizona, July, 1961
(905 pages)

This volume represents an empirical study aimed at solving specific problems encountered in particular material applications. Fundamental studies (involving chemistry, physics, and other sciences) on the state of the art in materials are included.

44374 EXAMINATION OF THREE 7.62MM M14 RIFLE BARRELS. J. M. Ingraham, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 739.1/2, September, 1961
(7 pages, 3 figures)

44374 (Continued)

Three M14 rifle barrels manufactured under contract, found to contain cracks after magnetic particle inspection, were examined to determine the cause of failure. The examination disclosed that these cracks had been present in the rifle-barrel bar stock prior to production heat treatment and had not been caused by proof-test firing of the weapon.

44375 HEAT TREATMENT OF HIGH-STRENGTH STEELS THROUGH CONTROL OF QUENCHING TEMPERATURE. S. V. Arnold, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 320.1/6, September, 1961
(11 pages, 5 figures, 2 tables)

Yield strength of suitable high-strength steels can be controlled by varying quenching temperature within the range of martensitic transformation followed by tempering at a single selected temperature. The mixed structures of martensite, low-temperature bainite, and retained austenite produced by this practice possessed good ductility and toughness.

The results suggest it should be possible to use the same salt bath both for a step-quench and also for tempering by maintaining a temperature slightly above the martensite start.

Yield strength would be controlled by air cooling to the proper temperature after the initial quench. This procedure should conserve furnace equipment, reduce handling, and expedite production. It is believed that a large number of high-strength steels are suitable for treatment by such practice.

44475 See Applications.

44533 REVIEW OF RECENT DEVELOPMENTS IN THE METALLURGY OF HIGH-STRENGTH STEELS. H. J. Hucek and A. R. Elsea, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 132, October 20, 1961
(1 reference, 2 pages, 1 table)

This report summarizes recent developments in the metallurgy of high-strength steels from July 1 to September 30, 1961. One very interesting report has come out on the subject of austempering. Since a large number of conflicting claims have been circulated regarding this process, the results of this investigation are presented.

Cobalt Base

44452 HIGH-PURITY COLUMBIUM. R. A. Ul'yanov, Y. P. Nechiporenko, and N. D. Tarasov, Library of Congress, Washington, D. C. AID Report No. 81-86, June 1, 1961; translated from Fizika Metallov i Metallovedeniye, Vol. 11, No. 3, March, 1961, pp. 461-464
(2 pages)

This article describes an attempt to develop a method of producing pure columbium in the solid state while maintaining its desirable mechanical properties. As a leading refractory metal, columbium is characterized by its high melting point, acceptable corrosion and erosion resistance, excellent strength at high temperatures, good weldability, and good ductility after welding. Also of note, especially with regard to these properties, is an observation made in the introductory paragraphs of the article linking the use of pure columbium to the development of a nuclear engine.

Nickel Base

44176 BRAZING OF COMPONENTS FOR SMALL GAS TURBINE ENGINES. M. J. Stern, Metal Progress, Vol. 80, No. 3, September, 1961, pp. 101-105, 120, 122, 124
(8 pages, 5 figures)

Brazing is a practical method of producing both simple and complicated assemblies with reproducible quality. Discussed here are techniques and controls employed at Boeing in joining engine components made of René 41 and other high-temperature alloys.

44287 THEORY AND APPARATUS FOR MEASUREMENT OF EMISSIVITY FOR RADIATIVE COOLING OF HYPERSONIC AIRCRAFT WITH DATA FOR INCONEL, INCONEL X, STAINLESS STEEL 303, AND TITANIUM ALLOY RS-120. W. J. O'Sullivan, Jr. and W. R. Wade, Langley Research Center, Langley Field, Virginia. NASA, TR R-90, 1961
(15 references, 24 pages, 27 figures)

Calculations of the cooling attainable by radiation at Mach numbers up to 11 and altitudes up to 100,000 feet are presented for a flat plate with turbulent boundary layer and alined with the wind. These calculations show the utility of radiation as a means of cooling high-supersonic and hypersonic aircraft under aerodynamic heating and the need for measurements of the total hemispherical emissivity of surfaces suitable for use on aircraft. The theory underlying the investigation and measurement of total hemispherical emissivity is presented. Readily duplicable apparatus suitable for performing the requisite measurements on a large variety of surfaces is described. The method of calibration and the techniques are given for using the apparatus to investigate the stability of the emissivity of surfaces, to measure the total emissivity as a function of angle to the surface, and to measure the total hemispherical emissivity of stable surfaces as a function of temperature. When Inconel, Inconel X, stainless steel 303, and titanium alloy RS-120 are cleaned to the bare metal, there can be produced, by heating in air, thin, smooth, adherent oxide coatings on the metals that do not flake off under rapid heating and cooling, are resistant to mild abrasion, emit diffusely, and have stable emissive characteristics. The total hemispherical emissivity of the Inconel coating was found to vary from 0.69 at 600 F to 0.82 at 1,800 F, that of Inconel X from 0.895 at 600 F to 0.925 at 2,000 F, that of stainless steel 303 from 0.74 at 600 F to 0.87 at 2,000 F, and that of titanium alloy RS-120 from 0.675 at 700 F to 0.715 at 1,500 F.

44336 INVESTIGATION OF THE EFFECTS OF MAGNETIC FLUX ON DISLOCATION MOVEMENT AND ALIGNMENT. A. C. Eckert, Jr. and H. V. Newman, General Motors Corporation, Indianapolis, Indiana. USAF, ASD, TR 61-217, June, 1961, Contract No. AF 33(616)-7116
(23 references, 28 pages, 10 figures, 3 tables)

Observations from previous work led to the hypothesis that under some conditions, magnetic flux influences the movement of dislocations within the grains of a ferromagnetic material. Based on X-ray diffraction extinction contrast, a technique has been derived from the work on

44336 (Continued)

this project that makes it possible to make a direct observation of dislocations in nickel foil samples; the dislocation movements can thereby be followed when the samples are subjected to magnetic flux. An unmistakable change in the imperfection structure was observed.

44488 SUPERALLOY MULTILAYER SANDWICH STRUCTURES FOR APPLICATION TO 1800°F.
H. Smallen, Welding Journal, Vol. 40, No. 9, September, 1961, pp. 423-s-432-s
(10 pages, 14 figures, 11 tables)

This program was part of an over-all maneuverable-satellite study to develop a suitable technique for fabricating a space-cabin structure capable of withstanding service temperatures for the operating time associated with re-entry into the earth's atmosphere. Inconel "X" and René 41 were selected for services up to 1500 and 1800 F, respectively. A sandwich construction was considered to provide the highest strength to weight structure.

The brazed structure in this investigation was required to withstand exposure to either 1500 to 1800 F for times associated with a space-vehicle re-entry into the earth's atmosphere. Only commercially available brazing alloys were chosen for evaluation. Nickel-base, semiprecious, and precious metal-base brazing alloys were selected for final evaluation.

Limited mechanical properties were obtained on the strengths of the superalloys subjected to a simulated braze and heat-treatment cycle and exposure at 1500 or 1800 F for periods of 1 and 5 min.

Engineering Steels

44166 HYDROGEN EMBRITTLEMENT OF HIGH STRENGTH STEELS. L. Domnikov, Metal Finishing, Vol. 59, No. 9, September, 1961, pp. 52-55
(3 references, 4 pages, 5 figures, 2 tables)

In this article are described the results of experiments on the determination of the effect of zinc plating from noncyanide baths on mechanical properties of steels, also on the effect of electroplating other metals such as cadmium and copper from cyanide solutions, chromium, tin, and lead from acid electrolytes.

44173 DEFORMATION OF METASTABLE AUSTENITE...AN INTERIM REPORT ON A NEW PROCESS. V. F. Zackay, W. M. Justusson, and D. J. Schmatz, Metal Progress, Vol. 80, No. 3, September, 1961, pp. 68-72, 126
(13 references, 6 pages, 6 figures, 1 table)

Mechanical properties of alloy steels strengthened by deformation in the metastable austenite "bay" of the T-T-T curve are affected in varying degrees by variations in grain size, tempering temperature, carbon content, and other metallurgical factors. Though a good deal of research has been performed, much work remains before the full story is known about this new hot-forming process.

44178 AUSTEMPERED-AND-RETEMPERED VERSUS QUENCHED-AND-TEMPERED STEEL AT HIGH YIELD STRENGTH LEVELS. S. V. Arnold, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 320.1/3, July, 1961
(20 references, 37 pages, 10 figures, 10 tables)

Tensile properties, including notched tensile and sustained notched tensile strength, and impact transition behavior of a 0.60 per cent carbon silicon-rich tool steel were determined at 220-ksi and 245-ksi yield-strength levels in order to compare effects of austemper-and-retemper heat-treatment practice with those of conventional quench-and-temper practice.

44284 TENSILE FRACTURE SURFACE CONFIGURATIONS OF A HEAT-TREATED STEEL AS AFFECTED BY TEMPERATURE. F. R. Larson and F. C. Carr, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 320.1/5, July, 1961
(18 references, 48 pages, 24 figures, 4 tables)

Fractured surfaces of tensile specimens of SAE 4340 steel heat treated to various strength levels and microstructures were examined at a magnification of 20X. Measurements were made of the size of each of three types of fracture-appearance zones present on each specimen. These measurements were correlated with testing temperatures over the range of -196 to +200 C.

Analysis of the quantitative amounts of three elements of fracture present, namely, fibrous, radial shear, and shear-lip, resulted in a descriptive explanation of the initiation and propagation of the fracture. These various modes of fracture zones change their relative size with changing testing temperature, which results in a transitional fracturing behavior in tension similar to that observed in other types of testing.

44293 See Titanium.

44301 THE APPLICATION OF HIGH ROTATIONAL SPEED TECHNIQUES TO THE STUDY OF THE ADHESION OF ELECTRODEPOSITS. W. H. Dancy, Jr., University of Virginia, Charlottesville, Virginia. USA, Report No. EP-4424-105-61U, Final Report, May, 1961, Contract No. DA-36-034-ORD-3125RD
(133 references, 143 pages, 20 figures, 23 tables)

Experimental work has been carried out to investigate the effects of various preplating treatments upon the adhesion of chromium electrodeposited on several basis metals. Most of the adhesion studies were done using 4140 steel as the basis metal; however, data are included for chromium deposited on: Cro-Mo-V steel; drill rod; and other related steels; chromium; and titanium. The effect on adhesion caused by variations of plating-bath composition, plating-bath temperature, and current density over the complete bright-plating range for chromic acid-sulfuric acid baths has also been investigated. Optimum chromic acid-sulfuric acid ratio for maximum adhesion is indicated. Some data are presented which indicate that the mild heat treatment of the plated article to eliminate hydrogen embrittlement also increases the tenacity of the bond between the coating and the substrate. Adhesion values were obtained by observing the rotational speed at which the deposits were separated from the basis metal by the forces normal to the interface created in a high-speed rotor. Knowledge of the speed at failure and the geometry of the system permits the value of the normal force at the point of failure to be calculated.

44409 INVESTIGATION OF STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS. R. F. Kimpel, Aerojet-General Corporation, Azusa, California. USA, Eighth Informal Progress Report No. L0414-01-8, June 30, 1961, Contract No. DA-04-495-ORD-3069
(3 pages, 3 tables)

In view of the fact that stainless steel (AISI Type 304 alloy) specimen holders are being employed to conduct the stress-corrosion testing of this program, and that the alloys being tested differ in composition from the holders, some concern has been expressed regarding the presence of galvanic couples (two dissimilar metals connected in an electrolyte) and the influence of galvanic corrosion upon the stress corrosion. The extent to which galvanic corrosion occurs and the distribution of galvanic currents on the stressed specimens (when coupling is made with the specimen holders) is not known at this time. However, experiments are being conducted to measure the potential of the various alloys when coupled with the specimen holders in the testing environments, the specimens being held in both stressed and unstressed states.

The environmental stress-corrosion testing of bent-beam samples is approximately 60 per cent complete. A table summarizes all of the test data accumulated to date.

U-bend test specimens are being prepared for conducting environmental stress-corrosion tests. These tests will serve to provide additional data to supplement the data now being accumulated with the bent-beam stress-corrosion tests.

44415 See Stainless Steels.

44419 AN INVESTIGATION OF METHODS FOR DETERMINING THE CRACK-PROPAGATION RESISTANCE OF HIGH-STRENGTH ALLOYS. J. D. Morrison and J. R. Kattus Southern Research Institute, Birmingham, Alabama. USN, Summary Technical Report, March 7, 1961, Contract No. NOas 60-6040-C, AD 257484 (9 references, 110 pages, 39 figures, 42 tables)

The purpose of the investigation described in this report was several-fold, covering mainly the following points: (1) to devise a simple crack-propagation specimen for evaluating high-strength sheet materials; (2) to determine the crack-propagation characteristics of several high-strength sheet materials; (3) to determine the effects of several experimental variables on the crack-propagation characteristics of some of these materials; and (4) to determine the validity of the crack-propagation specimen for predicting the biaxial strength of the high-strength sheet materials. A sheet specimen called the "shear-cracked" specimen was used extensively in the investigation. This specimen, which contains a central transverse crack or notch produced by means of a simple punch-and-die fixture, can be produced very rapidly and economically.

It was established that the crack-propagation properties obtained with the shear-cracked specimen were very similar to those obtained with fatigue-cracked specimens of the quench-hardenable and age-hardenable materials. A comparison of the crack-propagation properties obtained with sheet specimens and the burst strengths of model pressure vessels of two steels (AISI 4130 and AISI 4340) indicated that the sheet-type crack-propagation specimen may be useful in predicting the biaxial strength of materials heat treated to very high-strength levels (in excess of about 250,000 psi). At lower nominal strength levels, the crack-propagation specimen is apparently too "severe" a criterion of the biaxial strength behavior of sheet materials.

44446 PRELIMINARY MECHANICAL-PROPERTY DATA FOR SPECIMENS OF LADISH D-6ac STEEL FROM MINUTEMAN CHAMBERS THAT FAILED DURING STRUCTURAL TESTS. D. R. Collis, Aerojet-General Corporation, Sacramento, California. USAF, TN 61-20, March, 1961, Contract No. AF 33(600)-36610 (2 pages, 9 figures, 9 tables)

An investigation was made of the mechanical properties of specimens of Ladish D-6ac steel from flight-weight Minuteman chambers that failed during hydrostatic and other structural tests. The tests were designed to simulate in-flight loads and temperature conditions, and were made in accordance with the design development program and the confirmation test program.

Stainless Steels

44174 WHY DOES STAINLESS STEEL CORRODE? M. Sinclaire and E. Phillips, Metal Progress, Vol. 80, No. 3, September, 1961, pp. 92-96 (5 pages, 6 figures)

Unexpected corrosion of stainless steel can occur unless certain precautions are taken during fabrication and while parts are in service. Sensitization, carburization, sources of hydrochloric acid, and dirt are the main causes of failure. The authors explain why and point out the preventive measures that should be taken.

44175 THE EVOLUTION OF DUCTILE HIGH-TEMPERATURE BRAZING ALLOYS. D. C. Herrschaft, Metal Progress, Vol. 80, No. 3, September, 1961, pp. 97-100 (4 pages, 4 figures, 1 table)

Silver brazing alloys containing small amounts of lithium, indium, and palladium are now being used to bond stainless steel honeycomb, and alloys containing gold or palladium (or both) look promising for jet-engine brazing applications. Such brazing alloys are discussed.

44287 See Nickel Base.

44348 DEVELOPMENT OF NEW AND USEFUL ELEVATED-TEMPERATURE STEELS FOR AIRCRAFT APPLICATIONS. A. Kasak, V. K. Chandhok, and E. J. Dulis, Crucible Steel Company of America, Midland, Pennsylvania. USAF, ASD, TR 61-386, July 31, 1961, Contract No. AF 33(616)-7376 (72 pages, 19 figures, 17 tables)

This research project was aimed at developing a new heat-treatable stainless steel with an outstanding combination of strengths at ambient and elevated temperatures.

Of the large number of experimental compositions investigated, the 0.15C-14.5Cr-Mo-V-Co type steels indicated the best combination of desired characteristics and properties. Analysis of the effects of the alloying elements showed that molybdenum is an effective room- and elevated-temperature strengthening agent in these steels. The strengthening mechanism is associated with the precipitation of a FeMoCr intermetallic compound.

On the basis of the work on laboratory-sized heats, a nominally 0.15C-14.5Cr-5Mo-0.5V-13.5Co steel, Steel AFC 77, was selected for scaling up for production on mill facilities.

The properties of the mill-processed products were in good agreement with the properties of the laboratory-sized heats. In general, no significant variation in properties was attributable to the melting method or the product shape or size.

As a result of this project, a new hardenable high-strength stainless steel, referred to as Steel AFC 77, has been developed. Steel AFC 77 has very high strength (290,000 psi tensile strength) at the ambient temperature and retains its strength remarkably well up to about 1200 F (120,000-psi tensile strength at 1200 F). Indications of good formability and weldability have also been obtained. In addition to its superior mechanical properties, Steel AFC 77 is resistant to atmospheric corrosion and oxidation.

44409 See Engineering Steels.

44415 VERSATILE WELD TOOLING SAVES COSTS ON BOMARC. T. J. Bosworth and D. S. Hemminger, Western Metalworking, Vol. 19, No. 9, September, 1961, pp. 31-34
(4 pages, 7 figures)

The Bomarc missile program has presented a unique operation, with four different alloys being simultaneously TIG welded in a single production shop. Each alloy has its own fabrication characteristics which affect the welding operations and are reflected into the tooling and processing.

Six major pressure vessels were made—the helium bottle, boost oxidizer tank, boost fuel tank, boost propellant tank, and two ramjet fuel tanks, one each for Bomarc A and B missiles.

The first three tanks were of 17-7 PH stainless alloy, the fourth was made from 4330 modified steel, and the last two from 2219 and 6061 aluminum.

All welds in aluminum are made with straight butt joints, with welding being done in a single or double pass.

44416 NEW DESCALING METHOD CUTS SURFACE ATTACK ON SUPER ALLOYS; SAVES COSTS, MANHOURS. Western Metalworking, Vol. 19, No. 9, September, 1961, pp. 39-40
(2 pages)

A new chemical descaling technique significantly reduces intergranular surface attack on superalloys and stainless steels used in the aircraft and missile industry.

The method, named the sodium hydride RW 77 process, was developed by research engineers at Rohr Aircraft Corporation. It will not deter or interfere with fatigue life of the metal in its optimum condition.

Presently available acid descaling processes etch the metal underneath the oxide layer. The undercut scale then falls freely from the material. The RW 77 method minimizes or eliminates these deleterious surface conditions by working the descale material itself.

44429 EFFECT OF ENVIRONMENT ON THE CREEP PROPERTIES OF TYPE 304 STAINLESS STEEL AT ELEVATED TEMPERATURES. H. E. McCoy and D. A. Douglas. U. S. Atomic Energy Commission, Meeting held at Oak Ridge National Laboratory, Oak Ridge, Tennessee, TID-7597, February 26, 1960
(2 references, 40 pages, 29 figures, 5 tables)

The approach taken to this problem has been to study the behavior of Type 304 stainless steel in CO, CO_2, CH_4, H_2, N_2, and H_2O. It is believed that data from these tests represent the maximum effects which would be produced. Much of the testing program is now directed toward establishing the effects produced when an inert carrier is contaminated with a small partial pressure of one or more of these constituents. The fact that the metal capsules will operate over a temperature range from 1200 to 1700 F has increased the magnitude of the problem.

44532 REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF HIGH-STRENGTH STAINLESS STEELS. D. A. Roberts, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 131, October 13, 1961 (4 references, 3 pages)

This memorandum summarizes recent developments in the field of high-strength stainless steels and related alloys as disclosed to DMIC during the period of July 1 through September 30, 1961.

Although only a limited number of reports covering research work in this area were received, significant work was noted in the field of alloy development. Further information on the properties of existing alloys was also reported.

Iron Base

4422 THE MECHANISM OF HYDROGEN EMBRITTLEMENT OBSERVED IN IRON-SILICON SINGLE CRYSTALS. A. S. Tetelman and W. D. Robertson, Yale University, New Haven, Connecticut. USN, TR 3, September, 1961, Contract No. NOnr 609 (28)
(23 references, 20 pages, 15 figures, 1 table)

The technique of decorating dislocations was employed to investigate plastic deformation and fracture resulting from precipitation of hydrogen in iron-3 per cent silicon single crystals. It is shown that cracks are produced on $\{100\}$ planes inside crystals quenched from a hydrogen atmosphere at elevated temperatures or cathodically charged with hydrogen at room temperature. Plastic deformation in the vicinity of cracks, observed as arrays of decorated dislocations, is in conformity with previously calculated stress distributions about a crack containing an internal pressure. The fracture characteristics of crystals containing internal cracks were evaluated at 25 C and -196 C, and the results are related to the mechanism of hydrogen embrittlement.

LIGHT METALS

44206 See High-Strength Alloys.

44310 See Beryllium.

44415 See Stainless Steels.

44456 See Refractory Metals.

Beryllium

44310 A NEW STRUCTURAL CONCEPT TO CAPITALIZE ON THE POTENTIAL LIGHT WEIGHT OF BERYLLIUM. H. K. Hebeler, The Boeing Company, Seattle, Washington. Paper presented at the Sixth Symposium on Ballistic Missile and Aerospace Technology, October, 1961
(2 references, 19 pages, 5 figures, 3 tables)

A method new to the fabrication of beryllium is presented which minimizes the shortcomings of beryllium through the use of beryllium sheet bonded to an aluminum substructure. In the design concept shown, the brittle beryllium contains no stress concentrations. Instead, these are confined to the ductile aluminum. Since no beryllium machining is required, the cost and hygiene barriers are reduced. Current missile structural designs using machined sintered block materials have greater brittleness, much greater costs, and toxicity disadvantages as well as lower strength than the newer sheet-material design. Three beryllium interstages of this design have been fabricated and tested successfully under axial load as reported herein. One interstage contained a large bolted access door and bolted attachments to the forward and aft engines. The weight penalties of additional pieces of aluminum substructures did not significantly alter the ideal weight saving initially shown possible.

44430 OXIDATION OF BERYLLIUM. J. E. Antill and J. K. Higgins, U.K.A.E.A., Harwell. U. S. Atomic Energy Commission, Meeting held at Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 26, 1960, TID-7597, (6 references, 9 pages, 4 figures, 2 tables)

The object of the work reported in this paper was to extend the data for the behavior in carbon dioxide and oxygen to longer times of exposure and to determine the influence of variables in the fabrication of beryllium sheet. Rates of oxidation have been obtained for samples fabricated by different routes in carbon dioxide at 500-1000 C, oxygen at 700 C, and carbon dioxide containing water vapor at 700 C for times up to 5000 hours.

44473 PROPERTIES OF BERYLLIUM. H. H. Hausner, General Astrometals Corporation, Yonkers, New York. Paper received October, 1961
(17 references, 17 pages, 24 tables)

The 24 tables included represent the best available data on the structure, the physical, mechanical, and chemical properties of beryllium.

This compilation of beryllium data represents a first attempt to give the designer in the fields of aircraft, missiles, and nuclear engineering as much information for his calculations as possible. It is intended to extend these data in the future, as knowledge concerning beryllium progresses, and to bring these data up to date from time to time.

44494 BERYLLIUM FORGING. M. E. Cieslicki, Wyman Gordon Company, Worcester, Massachusetts. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(1 reference, 8 pages, 2 tables)

The fabrication of components of beryllium is discussed. With the purity level obtained in commercial practice and with the absence of an ingot-casting method that yields a forgeable product, powder-metallurgy techniques have been utilized. The shortcomings of the press-sintering technique gave reason to develop a new method using pressures in the range of 20,000 - 100,000 lb/sq in., sintering times from 1 second to 1 minute, and two temperature ranges (1600 and 1900 F).

44495 THE PRODUCTION OF BERYLLIUM ROD AND TUBING. J. C. Guest, D. N. Hewett, O. J. Jones, and W. A. Sallis, Tube Investments Technological Centre, Walsall, Staffs, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 16-18, 1961
(3 references, 7 pages, 8 figures, 5 tables)

A pilot plant and processes for the production of beryllium rods, tubing, and sections are described.

Preparation of billets for extrusion and subsequent processing are carried out in specially contained and ventilated plant, to overcome the health hazard. Process stages include powder consolidation by pressureless sintering, hot-sheathed extrusion, sheath removal by pickling, and finishing operations. The choice of material and design for billet sheathing is discussed.

Process inspections and metallurgical controls which insure uniform quality of the finished product are described.

44496 A PRECIPITATION REACTION IN COMMERCIALLY PURE BERYLLIUM. J. E. Meredith and J. Sawkill, Tube Investments Research Laboratories, Hinxton Hall, Cambridge, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(13 references, 5 pages, 9 figures)

Using dilute aqueous copper sulfate solution as an etchant, a series of microstructures has been obtained from the heat treatment of hot-extruded cast ingot beryllium that is indicative of a precipitation reaction. Hot-extruded metal is a supersaturated solid solution, and the solute may be precipitated by aging in the temperature range 550-750 C. The precipitation is localized initially at grain boundaries and around inclusions within the grains. This is followed by general grain precipitation and overaging at the boundaries. Re-solution takes place at 850 C, and the sequence of precipitation may be repeated. It is proposed that initial precipitation occurs at boundaries because they act as vacancy sources. Electron-probe microanalysis has shown that iron is involved in the reaction. Tensile tests have been made over the range 20-600 C on as-extruded metal and after aging. Aging results in substantial increases in tensile elonga-

44496 (Continued)

tion above 200 C. It is suggested that iron in solution limits high-temperature ductility. The removal of iron from solution by precipitation leads to higher elongations. After aging, the fracture in the range 20-200 C is mainly intergranular.

44497 TENSILE PROPERTIES OF HOT-EXTRUDED BERYLLIUM ROD AND TUBING. J. C. Guest and M. J. Hudson, Tube Investments Technological Centre, Walsall, Staffs, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(7 references, 5 pages, 6 figures, 3 tables)

Tensile properties of beryllium rod and tubing produced by hot extrusion of powder material have been determined over the temperature range 15-700 C.

Both longitudinal and transverse data were obtained on tubing, the latter being markedly inferior. Texture determinations show that this anisotropy results from preferred orientation developed in extrusion.

A limited investigation of heat treatments resulted in considerable improvements in ductility being obtained over the range 300-700 C.

44498 DEFORMATION AND ANNEALING PROCESSES IN BERYLLIUM. J. Sawkill, Tube Investments Research Laboratories, Hinxton Hall, Cambridge, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(16 references, 4 pages, 2 figures)

An analysis of the primary mode of fracture in beryllium, viz., basal cleavage, shows that the sequence of events leading to fracture is basal slip, the formation of bend planes, bend-plane splitting, and crack propagation. Nonuniform flow, due to constraints or inhomogeneities, is responsible for the formation of bend planes. As the temperature of deformation is increased in the range 0-400 C, the deformation becomes less inhomogeneous, the constraints less severe, and instead of showing sharp bend planes, the basal planes will bend continuously, giving higher ductility. On subsequent annealing the continuously bent grains will have a strong tendency to polygonize, with little grain refinement or change in texture. Polygonization can be avoided, and recrystallization induced, by annealing after large and homogeneous deformation. A precipitation heat treatment of hot-worked cast metal may allow large deformations to be achieved in the warm-working range. Subsequent annealing may result in substantial grain refinement and textural changes by recrystallization.

44499 DIVERGENT-BEAM X-RAY MICROSCOPY OF BERYLLIUM. K. J. Mackay, J. Sawkill, and D. R. Schwarzenberger, Tube Investments Research Laboratories, Hinxton Hall, Cambridge, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(10 references, 3 pages, 5 figures)

44499 (Continued)

The X-ray point-projection microscope is particularly suited to the study of beryllium, where research is required on the properties of single crystals, and on the mechanism of deformation in polycrystalline material.

With this instrument, a microradiograph, formed by variations in the thickness and composition of the specimen, is recorded at the same time as the divergent-beam diffraction pattern. The information obtained from these combined records has included the determination of orientation, lattice parameters and the degree of perfection in single crystals, and some aspects of deformation, fracture, and recrystallization in polycrystalline specimens.

44500 THE PURIFICATION OF BERYLLIUM BY A DISTILLATION PROCESS. E. W. Hooper and N. J. Keen, Atomic Energy Research Establishment, Harwell, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961 (8 references, 5 pages, 3 figures, 3 tables)

Commercial beryllium metal has been purified in gram quantities by a distillation process involving condensation in a heated tube, the temperature of which is graduated from 1300 C at the bottom to 800 C at the top. The interim results show that many of the impurities that are volatilized with beryllium pass to the cooler end of the condenser and the purest metal is collected in a zone in the temperature range 1100-1000 C. The anomalous behavior of certain impurities is described.

44501 THE OXIDATION OF BERYLLIUM IN CARBON DIOXIDE. P. J. Phennah, M. W. Davies, and B. C. Woodfine, General Electric Company, Limited, Atomic Energy Division, Erith, Kent, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961 (9 references, 6 pages, 21 figures, 1 table)

The oxidation behavior of two samples of commercial beryllium in CO_2 and in CO_2/H_2O and $CO_2/CO/H_2O$ mixtures at pressures up to 150 lb/sq in. has been studied over the temperature range 600-750 C. The extent of oxidation was assessed by weight-gain measurements and by metallographic examination, and the oxide scales were also examined by X-ray and electron-diffraction techniques. The two samples of beryllium were fabricated from powder of the same specification by hot pressing and by cold pressing, sintering, and warm extruding, respectively. With dry CO_2 the oxide was protective, but in a number of tests rate transitions were observed. In the CO_2H_2O mixtures the oxidation rate initially decreased with time but eventually breakaway oxidation, i.e. an accelerating rate, occurred. The time to the onset of breakaway oxidation was related to the temperature and to the gas composition. The mechanism of the oxidation process is discussed with particular reference to the occurrence of breakaway oxidation.

44502 THE PRESSURELESS SINTERING OF BERYLLIUM POWDER TO BILLETS FOR HOT EXTRUSION. G. L. Reeves and R. L. Keeley, Tube Investments Technological Centre, Walsall, Staffs, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(3 references, 6 pages, 10 figures, 4 tables)

The production of cylindrical and tubular billets is described, and variables affecting packing density, sintered density, shrinkage, the cracking of hollows, and grain size have been investigated for two grades of powder. The densities of the billets sintered at 1200 C for 5 hours for standard powder and at 1230 C for 5 hours for high-purity powder, ranged from 72 to 98 per cent of the theoretical value. Hot extrusion completed the consolidation of the powder.

44503 RECENT BERYLLIUM RESEARCH IN CANADA. W. D. Bennett, Canadian Westinghouse Company Limited, Hamilton, Ontario, Canada. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(17 references, 6 pages, 10 figures)

A program of evaluating commercially available grades of beryllium rod for reactor applications has produced results which are of interest in diagnosing the cause of room-temperature brittleness in beryllium. Axial tensile tests indicate that beryllium changes from a ductile to a brittle metal over a relatively narrow temperature range and also exhibits a double-yield-point phenomenon under certain conditions of testing. An interpretation of the results in terms of impurity—dislocation interaction explains the change from fibrous to cleavage-type fractures with changes in temperature and strain rate, predicting that the ductile range could be extended to room temperature by a combination of grain refinement, increased purity, and a reduction in strain rate. Metallographic studies confirm that the drop in ductility at higher temperatures is associated with the onset of intergranular fracture and demonstrate the occurrence of three types of fracture: cleavage below the transition, intergranular at the higher temperatures, and a mixture of cleavage and fibrous in the intermediate range. There is a significant difference between the mechanical properties of metal water-quenched after 24 hours at 900 C and metal slow-cooled.

44504 AN INVESTIGATION INTO THE BRAZING OF BERYLLIUM. W. Vickers, English Electric Company Limited, Atomic Power Division, Whetstone, Leicester, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(6 references, 5 pages, 6 figures, 3 tables)

Attempts to braze beryllium have been carried out using a variety of braze metals. Successful joints were obtained with H10, SCP3, silver, SCP5, and SCP6 alloys. The brazing temperature of these alloys varied from 800-1100 C.

44504 (Continued)

On annealing specimens in dry CO_2 (less than 10 ppm water) at 600 C, there was severe attack at the beryllium/braze interface.

The results are discussed from the brazing viewpoint and in terms of using brazed joints in an advanced gas-cooled reactor.

44505 COMPATIBILITY OF BERYLLIUM WITH VARIOUS REACTOR MATERIALS. W. Vickers, English Electric Company Limited, Atomic Power Division, Whetstone, Leicester, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(7 references, 5 pages, 7 figures, 9 tables)

The compatibility of beryllium with alumel, chromel, copper, mild steel, molybdenum, nickel, niobium, stainless steel, tantalum, titanium, thermoflex, uranium, zirconium, zirconium alloy (Zr - ½Cu - ½Mo), sintered alumina, sintered magnesia, sintered zirconia, powdered alumina, and powdered zirconia has been studied at 550 and/or 600 C. The tests were carried out in vacuum and/or carbon dioxide containing less than 10 ppm by weight of water.

Attempts to retard the reaction with mild steel and/or stainless steel at 600 C have been made by coating the steels with chromium, alumina, zirconia, silicon carbide, tantalum carbide, tungsten carbide, and a nitrogen-diffusion layer.

Three annealing times up to 2000 hours have been used, and the extent of reaction and the reaction equations have been determined where possible.

A general discussion of the results is given.

44506 DEVELOPMENT OF NON-DESTRUCTIVE TESTING TECHNIQUES FOR THIN-WALL BERYLLIUM TUBING. R. W. McClung, Union Carbide Corporation, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(4 references, 6 pages, 16 figures)

This paper discusses briefly the need for testing of beryllium tubing and some of the problems that have been encountered during the development program. Mention is made of typical discontinuities which are detected. Low-voltage radiography is presented as one of the most useful techniques. Extensive efforts, including helium atmospheres and dark-room, bare-film exposure techniques, were necessary to achieve this state of efficiency on material with such a low-radiation absorption coefficient. The problems encountered because of the very high velocity of ultrasound in beryllium are described. The solutions to these problems and the accomplishments using both resonance and pulse-reflection techniques are presented. The present state of usefulness of the encircling-coil eddy-current technique is discussed. Other more standard techniques included are liquid-penetrant inspection, pneumatic gaging, and mass-spectrometer helium-leak tests. Comparison is made of these various testing methods on the basis of cost and capabilities.

44507 VACUUM FURNACE BRAZING OF BERYLLIUM. E. F. Westlund, University of California, Livermore, California. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961, Contract No. W-6405-ENG-48
(1 reference, 5 pages, 7 figures, 3 tables)

Vacuum brazing techniques have been developed for joining beryllium to titanium, stainless steel, and to itself using silver as the filler. Shear strengths of about 20,000 lb/sq in. were obtained for all three types of brazes. When brazing beryllium to titanium or to stainless steel, excessive brazing temperatures or holding times result in low-strength brazes. Both brazes can be made at temperatures as low as 900 C, which is 60 below the melting point of pure silver.

Initially, difficulty was experienced in obtaining consistently good brazes when joining beryllium to itself owing to poor wetting by the silver. This was overcome by adding a small amount of titanium hydride to the beryllium contact surface. High-strength brazes were consistently produced by this method at temperatures from 960 to 1070 C, showing that overheating was not a problem.

44508 ELECTRON-BEAM FUSION WELDING OF BERYLLIUM. W. T. Hess, H. J. Lander, S. S. White, and L. M. Schetky, Alloyd Corporation, Cambridge, Massachusetts. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(6 references, 4 pages, 10 figures)

The prime causes of autogenous weld failure in the metal beryllium are vaporization, out-gassing, thermally induced stress-cracking, and excessive grain growth. Electron-beam welding provides a means of obviating these problems. Necessary to successful welding is the control of heat flow, chamber pressure, and weld-energy input. Welds can be made which are mass-spectrograph leak-tight and exhibit base-metal mechanical properties. A discussion of techniques and results will be presented as applied to hot-pressed and to rolled-sheet material.

44509 AUTOMATIC AND MANUAL BRAZE-WELDING TECHNIQUES FOR BERYLLIUM. W. J. Marcellin, University of California, Livermore, California. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961, Contract No. W-7405-ENG-48
(4 references, 6 pages, 6 figures, 3 tables)

Procedures for braze-welding beryllium by the tungsten-arc (non-consumable electrode) and metal-arc (consumable electrode) inert-gas-shielded processes are described. These procedures provide for two general fabrication conditions for the purpose of controlling base-metal temperatures and limiting base-metal cracking. These conditions limit the braze-welding heat inputs above and below 2500 joules/in. of weld. Braze-welds are made with aluminum-5 or 12 per cent silicon alloy or 99.9 per cent pure silver as the braze material.

The natures of the various welding arcs are discussed and data presented to show their effects on the beryllium microstructure. High-

44509 (Continued)

speed photographs show the metal transfer of dip and spray consumable-electrode arcs. The equipment necessary to obtain the required arc characteristics is considered.

44510 DUCTILE BERYLLIUM COMPOSITES BY LIQUID-PHASE SINTERING. F. A. Crossley and R. J. Van Thyne, Armour Research Foundation of Illinois Institute of Technology, Chicago, Illinois. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(13 references, 6 pages, 6 figures, 2 tables)

Liquid-phase sintering to produce an envelope-type microstructure has shown considerable promise for producing ductile beryllium composites. Composites containing aluminum or silver as the matrix, ternary additions for promoting sinterability, and quaternary additions for strengthening the matrix have been investigated. The best results were obtained with a pressure-sintered compact of the system beryllium-silver-aluminum-germanium. This compact tested in uniaxial compression had properties as follows: 0.2 per cent proof stress 52,400 lb/in^2, true stress at initiation of cracking at the surface 97,000 lb/in^2 (engineering stress of 130,000 lb/in^2), total plastic deformation at crack initiation 22 per cent and modulus of elasticity 22 x 10^6 lb/in^2. The matrix content of this material was calculated from the density to be about 3 per cent by volume. Density of 2.07 g/cc gives a modulus: density ratio of this compact 2.9 times that of steel.

44511 REACTION KINETICS OF HIGH-TEMPERATURE CORROSION OF BERYLLIUM IN AIR. W. G. Bradshaw and E. S. Wright, Lockheed Missiles and Space Division, Palo Alto, California. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961, Contract No. NOrd 17017
(8 references, 5 pages, 8 figures, 2 tables)

This investigation was undertaken to determine the corrosion rate in air of beryllium at temperatures approaching its melting point. It was carried out in air at near-atmospheric pressures over the range 930-1295 C. The reaction rate was followed by both gravimetric and manometric means.

44512 EFFECT OF PROCESS VARIABLES ON THE BRITTLE BEHAVIOUR OF BERYLLIUM SHEET. C. J. Glemza, The Martin Company, Baltimore, Maryland. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961, Contract No. AF 33(600)-40648
(11 references, 5 pages, 9 figures, 2 tables)

Beryllium sheets, produced by three techniques, (hot-pressed, hot cross-rolled and hot-upset) were subjected to various mechanical tests.

44512 (Continued)

Conventional tests, i.e., tension, compression, and notch tension, did not provide an adequate index of the brittleness as it relates to crystallographic texture, process variables, and size-effect. A clearer characterization of the relative mechanical behavior of the beryllium sheets was indicated from the results of constant-moment bend-ductility tests. Bend-test specimens of varying width and thickness were employed to establish quantitatively the plastic strain behavior of the test materials as a function of size. In general, the ductile failure of beryllium sheet in bending was related to the strain-hardening rate in tension. A forged-upset sheet exhibited good ductile behavior in bending, similar to an isotropic hot-pressed sheet, and relatively high-mechanical properties values equal to those of a hot cross-rolled sheet. The results also indicated that the ductile behavior of beryllium sheet depends on: (1) the degree of anisotropy developed by reduction during hot working. (2) the stress state, and (3) to a large extent on the temperature employed during reduction.

44513 A FRESH LOOK AT THE PROBLEMS IN BERYLLIUM. R. F. Bunshah, University of California, Livermore, California. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(36 references, 9 pages, 2 figures)

The current status of beryllium metallurgy is reviewed. The nonsystematic variation in the mechanical properties, particularly the low room-temperature properties and the ductility minimum around 600 C, are its most disturbing features. Recent work shows that the 600 C ductility minimum can be eliminated by overaging of controlled compositions, which means that commercial beryllium may be considered as a complex, unstable age-hardening alloy rather than as a somewhat impure dilute alloy. The implications of this as regards the room-temperature properties are discussed. Some comments on the technological problems and analytical requirements are made.

44514 INHIBITION OF BREAKAWAY OXIDATION OF BERYLLIUM IN CARBON DIOXIDE. R. Smith, W. I. Stuart, W. J. Van Peer, and G. Price, Australian Atomic Energy Commission, Lucas Heights, Australia. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(10 references, 5 pages, 9 figures, 4 tables)

Oxidation tests have been made at 700 C in carbon dioxide containing 2 per cent water vapor to investigate the effects of intergranular oxide content on the "breakaway" or rapidly accelerating type of oxidation observed when beryllium is oxidized in wet carbon dioxide. Weight-gain/time curves were determined for different materials, and the nature of the processes was investigated by metallography combined with electron and X-ray diffraction. It was found that breakaway oxidation was effectively inhibited in beryllium made from powder which, before consolidation, was oxidized at 800 C in oxygen for $\frac{1}{2}$ - $1\frac{1}{2}$ hours.

44515 THE EXTRUSION OF BERYLLIUM. W. J. Wright and J. M. Silver, Australian Atomic Energy Commission, Lucas Heights, Australia. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(8 references, 4 pages, 5 figures)

The equipment and technique for the extrusion of beryllium within a mild steel sheath are described, and the limitations of the techniques are discussed.

The use of a lead glass as a lubricant reduces the extrusion pressure for mild steel by 15 per cent at 1050 C; the advantages of the application of glass lubricants in the extrusion of beryllium without a mild steel sheath are discussed.

44516 THE REACTIONS OF BERYLLIUM WITH WET CARBON DIOXIDE. W. J. Werner and H. Inouye, Union Carbide Corporation, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(5 references, 5 pages, 7 figures, 4 tables)

The reactions of beryllium with wet and dry CO_2 were found to be parabolic in the temperature range 550-720 C for times up to 1000 hours. At 725 C, a "breakaway" reaction was observed in wet CO_2 after 60-70 hours. Reaction products were found to be BeO and Be_2C, both increasing with time and temperature.

The reactions between beryllium, which contains carbon as an impurity, and wet helium were characterized by an initial rapid rate of reaction followed by a protective type of oxidation similar to that observed in dry CO_2. This behavior is believed to be associated with decarburization during the early stages of the test.

44517 THE STABILITY OF THE HIGH-TEMPERATURE PHASE IN BERYLLIUM AND BERYLLIUM ALLOYS. S. H. Gelles, J. J. Pickett, E. D. Levine, and W. B. Nowak, Nuclear Metals, Inc., Concord, Massachusetts. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961, Contract No. AT(30-1)-1565
(11 references, 7 pages, 10 figures, 3 tables)

An investigation is in progress to determine the stability and mechanical properties of the body-centred cubic phase that exists just below the melting point of beryllium-rich alloys. Differential thermal analysis (DTA) has been applied to alloys of beryllium in each of the following systems: barium, cerium, chromium, cobalt, copper, iron, lanthanum, manganese, nickel, niobium, palladium, platinum, silicon, silver, vanadium, zirconium, nickel—cobalt, nickel—copper, nickel—iron, nickel—palladium, nickel—cobalt—iron, and nickel—cobalt—manganese. The DTA has established fairly well the β-phase field in the systems of beryllium with chromium, cobalt, copper, and nickel; tentative β-phase fields have been constructed for the systems of beryllium with iron, manganese, silicon, and silver. The remaining systems are still being studied.

44518 BERYLLIUM FABRICATION TECHNOLOGY. M. E. Tatman, Lockheed Aircraft Corporation, Missiles and Space, Sunnyvale, California. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961 (2 references, 8 pages, 4 figures, 4 tables)

The development of materials capable of withstanding the thermal-structural environments of missile flight is discussed. Because of its characteristics, beryllium appeared attractive and was immediately considered. However, at that time, beryllium was relatively unknown and data on design and fabrication were limited. The extensive development effort which qualified beryllium as a suitable material for use on missiles and space craft is described.

As reported in this paper, alternative types of forming and joining methods were investigated. Methods of forming included hot-formed plate, hot-pressed canned material, back-extrusion, and high-temperature isostatic pressing. Joining methods investigated included brazing, arc welding, adhesive bonding, and mechanical methods.

44519 GRAIN REFINEMENT OF INGOT SHEET BERYLLIUM BY WARM WORKING AND ANNEALING. C. I. Bort and A. Moore, Atomic Weapons Research Establishment, Aldermaston, Berks., England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961 (3 references, 4 pages, 8 figures)

The effect of warm working (below 700 C) on the subsequent annealing behavior of rolled-ingot beryllium sheet at high temperatures has been studied. With optimum working conditions and annealing conditions uniform and equiaxed, grain sizes of about 30μ have been achieved which show about 12 per cent elongation at 20 C when tested in uniaxial tension.

44520 THE EFFECT OF PURITY AND ORIENTATION ON THE DEFORMATION OF BERYLLIUM SINGLE CRYSTALS. G. Greetham and A. J. Martin, Atomic Weapons Research Establishment, Aldermaston, Berks., England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961 (16 references, 6 pages, 10 figures, 5 tables)

Single crystals of beryllium have been prepared from extruded rods of vacuum-cast electrolytic ingot by a floating-zone technique. Two or more tensile specimens were prepared from these refined bars, in which the purity varied along the bar, and were tested at temperatures between -196 and 600 C. The results are discussed, and it is concluded from comparison with earlier work that further purification of beryllium could lead to a decrease in the ductile-brittle transition temperature for extruded rod.

44521 AN EVALUATION OF THE HYDROGEN CONTENT OF COMMERCIALLY PURE BERYLLIUM AND ITS EFFECT UPON THE DUCTILE-TO-BRITTLE TRANSITION TEMPERATURE. P. Cotterill, R. E. Goosey, and A. J. Martin, Atomic Weapons Research

44521 (Continued)

Establishment, Aldermaston, Berks., England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(26 references, 7 pages, 7 figures, 5 tables)

The paper describes the use of a vacuum-fusion technique for the determination of the hydrogen content of beryllium. It is concluded that the solubility of hydrogen in solid beryllium is negligibly low, the hydrogen evolved during analysis being directly attributable to a surface adsorption effect. The use of an axially aligned tensile-testing technique has shown that the room-temperature brittleness of beryllium is due to an orthodox ductile-brittle transition effect occurring in the range 100-200 C; this being uninfluenced by any attempt at hydrogenation.

44522 HIGH-TEMPERATURE DUCTILITY OF POWDER-FABRICATED BERYLLIUM AT HIGH AND LOW STRAIN RATES. G. C. Olds, T. Raine, J. A. Robinson, and A. G. Todd, Associated Electrical Industries, Limited, Rugby, and Associated Electrical Industries, Limited, Manchester, England. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(3 references, 5 pages, 7 figures, 1 table)

The ductility of several batches of powder-fabricated, cross-rolled beryllium has been measured at a high strain rate of 10 per cent/minute and low strain rates of 0.1 per cent/hour or less, between room temperature and 700 C. Ductility/temperature curves showed maxima, dependent on strain rate, falling to low ductility at high temperatures. As strain rate decreased, the minimum in high-temperature ductility decreased; it fell to 2-3 per cent at 600 C at 0.1 per cent/hour and rupture elongations below 1 per cent were found at creep rates of the order of 0.001 per cent/hour. Aluminum and possibly other impurities appeared to contribute to high-temperature intergranular failure; an overaging heat treatment softened the material and improved high-temperature ductility at high strain rate, but had little effect at low strain rates, where it is believed that excessive grain-boundary impurities, such as oxide, limited the strain obtainable before cracking. A working-design creep stress for the material was under 1000 lb/in^2 at 600 C; both higher creep strength and ductility at high temperature should be obtainable in a cleaner material, with controlled alloying to increase grain-boundary strength.

44523 THE FLOW AND FRACTURE CHARACTERISTICS OF ZONE-MELTED BERYLLIUM. M. Herman and G. E. Spangler, Franklin Institute, Philadelphia, Pennsylvania. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(16 references, 7 pages, 2 figures, 2 tables)

The purpose of this investigation was to determine whether an "impurity effect" was associated with the basal plane ductility of beryllium.

44523 (Continued)

Floating-zone-type zone-melting procedures were used both to purify and produce beryllium single crystals. These crystals were tested in tension with their orientation arranged to yield basal plane slip. The critical resolved shear stress was observed to vary from 2400 to 500 lb/in^2, decreasing with increased purification. The glide strain varied from 16 to 220 per cent, increasing with increased purification. It was concluded that an "impurity effect" exists. The effect of impurities and testing conditions on the ductility of beryllium, together with the manner in which zone melting affected impurity removal, is discussed.

44524 ON THE BEHAVIOUR OF DISLOCATIONS IN BERYLLIUM. H. G. Wilsdorf and F. Wilhelm, The Franklin Institute Laboratories, Philadelphia, Pennsylvania. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(5 references, 4 pages, 3 figures, 1 table)

Dislocation patterns have been examined with the electron microscope, using diffraction contrast mechanism, in single-crystalline and polycrystalline beryllium specimens of commercial and Pechiney flake purity. The main results of the investigation are: (1) glide dislocations are strongly hindered in their movements and often pinned by small precipitates in beryllium of commercial purity; (2) dislocation tangles have been observed in deformed Pechiney flake beryllium; the presence of round as well as elongated prismatic dislocation loops is in evidence; (3) dislocations on different slip systems may react to form incipient networks; (4) in the Pechiney flake material, in which obstacles are comaratively rare, the dislocations have a pronounced tendency to align along crystallographic directions, indicating a strong Peierls—Nabarro force; (5) the dislocations were always immobile at the stress created by a high-intensity electron beam in the microscope; (6) dislocation arrays of very high density have been found to lie in $(1\bar{2}10)$.

44525 A STUDY OF MECHANICAL ANISOTROPY AND HETEROGENEITY IN BERYLLIUM SHEETS. C. Gasc, Laboratoire de Metallurgie Physique, Poitiers, France. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(6 references, 4 pages, 9 figures)

Considerable and varied experience has made it possible to review some of the aspects of the brittleness of beryllium at room temperature. Studies of preferred orientation by means of pole figures, supplemented by tensile tests, have shown that, with polycrystalline metal, heavy plastic deformation is possible only by certain modes of slip, requiring special textures. Again, the scatter in tensile-test results must derive from the marked structural inhomogeneity of the sheets. The latter is due, in particular, to the various processes of recrystallization, which are practically unexplored in this metal.

44525 (Continued)

The effect of impurities is of great importance, and appears to depend on the size and distribution of impurity constituents, which themselves depend on earlier thermal treatments.

44526 THE WELDING OF BERYLLIUM CANS. P. Malhomme and P. Thome, Centre d'Études Nucleaires de Saclay, Gif-sur-Yvette, France. Preprint of paper submitted to the Institute of Metals, Conference on the Metallurgy of Beryllium, London, England, October 18, 1961
(4 pages, 9 figures)

Work on the welding of beryllium was undertaken with a view to its possible application to EL.4 fuel elements, one of the suggested versions of which consists of an assembly of rods sheathed in beryllium. In this study two types of fusion welding were considered: one involving electron bombardment and the other inert-gas arc welding. The tests were made on two types of closure: welding from above and lateral welding, both preceded by various surface treatments, namely, chemical cleaning, electrolytic polishing, or simple degreasing. A study of the effect of nonmetallic impurities on welding has also been begun.

Titanium

44172 A REVIEW OF RECENT DEVELOPMENTS IN TITANIUM AND TITANIUM ALLOY TECHNOLOGY. R. A. Wood, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 126, September 15, 1961
(18 references, 6 pages)

This memorandum briefly reviews selected information on new developments in titanium metallurgy that became available to DMIC during the period from June through August, 1961.

Based on the number of reports concerning titanium-alloy technology, a major interest currently is centered around the Ti-13V-11Cr-3Al all-beta alloy and the Ti-8Al-1Mo-1V, Ti-7Al-12Zr, and Ti-5Al-5Sn-5Zr super alpha alloys. Other titanium-alloy grades, particularly those in the Department of Defense Sheet Rolling Program, still receive a large proportion of the research effort. Researches toward improving the fabrication, joining, and forming processes generally utilize the above alloy grades. Very little information on the development of new titanium-alloy compositions is available.

44255 DETERMINATION OF OXYGEN IN TITANIUM. T. A. Sullivan, B. J. Boyle, A. J. Mackie, and R. A. Plott, U. S. Department of the Interior, Bureau of Mines, Washington, D. C. RI 5834, 1961
(31 references, 30 pages, 6 figures, 3 tables)

The work described in this report was undertaken to evaluate and develop techniques for determining the oxygen content of titanium and titanium alloys. Early investigations of volatilization techniques involving halogenation were unsuccessful. Later efforts were concentrated on evaluating vacuum fusion and inert-gas fusion techniques. Two vacuum fusion methods and an inert-gas fusion method were found to be satisfactory in the 0.02 to 1.00 per cent oxygen range. These methods are described in detail. The coefficient of variation by any of the three methods is approximately 5 per cent. While the main portion of this paper is devoted to the vacuum and inert-gas fusion methods, a resumé of other suggested methods for analyzing titanium for oxygen also is given.

44260 THIN, TWIN CHARPY SPECIMENS SPACED FOR TESTING SHEET MATERIALS. A. A. Iannelli and F. J. Rizzitano, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 406.5/1, July 1961
(4 references, 20 pages, 11 figures, 1 table)

Charpy impact tests on titanium alloy Ti-155A, heat treated to various strength levels, have been carried out for specimens of standard and reduced thicknesses. The thin specimens have been tested by a newly developed technique which permits testing of specimens by simply cementing them together in pairs with spacers between them. The tests reveal: (a) a nonlinear relationship between thickness of specimen and Charpy impact values and (b) the nonlinearity is more prominent at high temperatures, with the thicker specimens absorbing considerably more impact energy.

Charpy impact nergy-temperature curves for standard, one-half, one-third, one-fourth, one-sixth, and one-eighth of standard thicknesses are presented.

44293 REVIEW OF RECENT DEVELOPMENTS IN THE EVALUATION OF SPECIAL METAL PROPERTIES. J. E. Campbell, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 128, September 27, 1961
(7 references, 8 pages, 2 figures, 2 tables)

This is the third memorandum on the evaluation of the mechanical properties of metals by special techniques or for special applications. It covers information that became available to the Defense Metals Information Center from June through August, 1961.

Topics covered include: evaluation of titanium for liquid-hydrogen tankage, effects of small cracks in reducing the strength of tensile specimens of H-11 and SAE 4340 steels and Ti-6Al-4V and Ti-13V-11Cr-3Al alloys, and the determination of hydrogen embrittlement in metals.

44301 See Engineering Steels.

44402 PHYSICAL METALLURGY OF TITANIUM ALLOYS. B. L. Averbach and N. B. Bever, Massachusetts Institute of Technology, Cambridge, Massachusetts. USN, Final Report, September 19, 1961, Contract No. NOnr-1841(02)
(6 pages)

Additional work on the basic phase transformations involved in the heat treatment of titanium alloys was carried out. The investigation was concerned with a wide range of problems and included such topics as an X-ray method for the quantitative determination of the beta phase. Studies of the mechanical properties, phase transformations and aging characteristics of several alloys, and measurements of short-range order in titanium-molybdenum alloys are discussed.

44409 See Engineering Steels.

44444 TITANIUM DEVELOPMENT PROGRAM, VOLUME 1. C. W. Alesch and S. R. Carpenter, General Dynamics/Convair, San Diego, California. USAF, ASD, TR 61-7-576, Final Technical Engineering Report, May, 1961, Contract No. AF 33(600)-34876
(numerous pages, numerous figures, numerous tables)

Ti-4Al-3Mo-1V alloy was selected, in the basic evaluation, over Ti-2.5Al-16V and Ti-6Al-4V because of its greater ability for satisfying engineering-properties requirements, acceptability of mode of heat treatment, and over-all manufacturing capabilities for air-frame construction employing solution heat treated and aged titanium alloys. Ti-13Cr-11V-3Al was selected, in the supplemental limited evaluation, over Ti-5Al-2.75Cr-1.25Fe due to its superior mechanical-property values and spot-weld strength values.

44445 TITANIUM DEVELOPMENT PROGRAM, VOLUME 2. C. W. Alesch and S. R. Carpenter, General Dynamics/Convair, San Diego, California. USAF, ASD, TR 61-7-576, Final Technical Engineering Report, May, 1961, Contract No. AF 33(600)-34876
(numerous pages, numerous figures, numerous tables)

44445 (Continued)

Detailed incoming inspection data, inspection control chart data, creep-test curves, and curves comparing properties of various alloys are recorded herein. Interpretative discussions are found in Volume 1.

44528 TITANIUM DEVELOPMENT PROGRAM, VOLUME 3. A. P. Langlois, J. F. Murphy, and E. D. Green, General Dynamics/Convair, San Diego, California. USAF, ASD, TR 61-7-576, Final Technical Engineering Report, May, 1961, Contract No. AF 33(600)-34876
(297 pages, 198 figures, 13 tables)

Ti-4Al-3Mo-1V alloy was found to be superior to Ti-2.5Al-16V and Ti-6Al-4V considering the over-all forming and joining characteristics determined by the basic fabricability evaluation. In the supplemental evaluation of two additional alloys, the Ti-13V-11Cr-3Al was found to be superior to Ti-5Al-2.75Cr-1.25Fe in mechanical-property values and spot-weld strength characteristics. The forming, joining, machining, and chemical processing of these alloys are discussed.

44529 TITANIUM DEVELOPMENT PROGRAM, VOLUME 4. A. P. Langlois, J. F. Murphy, and E. D. Green, General Dynamics/Convair, San Diego, California. USAF, ASD, TR 61-7-576, Final Technical Engineering Report, May, 1961, Contract No. AF 33(600)-34876
(168 pages, 124 figures, 3 tables)

The fabrication of complex parts for both present and future airframe units from the Ti-4Al-3Mo-1V alloy can be achieved with proper design and consideration of alloy forming and joining limitations. Tooling concepts and the manufacture of tail cone, leading edge, canted fuselage bulkhead assemblies, engine bleed air ducts, and panels are discussed.

44530 TITANIUM DEVELOPMENT PROGRAM, VOLUME 5. G. D. Lindeneau, D. H. Love, J. K. Neary, H. A. Buehler, and G. F. Foelsch, General Dynamics/Convair, San Diego, California. USAF, ASD, TR 61-7-576, Final Technical Engineering Report, May, 1961, Contract No. AF 33(600)-34876
(362 pages, 92 figures, 5 tables)

Typical airframe structures, fuselage frames, wing leading edge, bleed air ducts, tail cone, shear panels,and compression panels of Ti-4Al-3Mo-1V and Ti-13V-11Cr-3Al were subjected to test loads in increasing increments of 100 degrees from room temperature to maximum temperatures of 800 F and 900 F, depending on the part. Riveted and resistance-welded construction was evaluated in the fuselage frame and wing leading edge. Other components were either fusion welded, resistance welded, riveted,or brazed. Components were subjected to static and repeated loadings with the exception of compression panels which had axial and side loads supplied. All components satisfactorily withstood static test loads. Under repeated load test, the resistance-welded fuselage frame and wing leading edge, although adequate, did not perform as well as the riveted versions. Repeated load tests of resistance-welded shear panels showed marginal results. Other components performed satisfactorily under repeated load conditions.

Silicon

44161 SINGLE CRYSTAL SILICON OVERGROWTHS. A. Mark, Journal of the Electrochemical Society, Vol. 108, No. 9, September, 1961, pp. 880-885 (3 references, 6 pages, 8 figures)

The pyrolytic process for the vapor phase deposition of single-crystal silicon overgrowths on parent substrates is described. This method utilizes the dissociation of silicon tetrachloride by hydrogen in an open tube flow process. Free-energy and vapor-pressure data are plotted for $SiCl_4$, BCl_3, and PCl_3 showing the dissociation relationship between these reacting species for junction formation. Photographs indicate the dependence on temperature of the silicon morphologies that deposit on the substrates, other variables being held constant. Because of the low thermal conductivity of silicon, emphasis is placed on direct contact heating of the silicon substrates to control overgrowth quality. Large temperature gradients were found to exist on the substrate surface with indirect heating by the reactant gases.

NONMETALLICS

44455 PREPARING ZIRCONIUM DIBORIDE DIRECTLY FROM ZIRCON. P. G. Cotter, U. S. Department of the Interior, Bureau of Mines, Washington, D. C. RI 5770, 1961
(14 references, 9 pages, 4 figures, 4 tables)

In commercial practice, zirconium diboride is ordinarily made by reacting the metal, the metal hydride, or the metal oxide with boron or with compounds that release boron.

The theory derived from the work of others was that zirconium diboride might be made directly from zirconium silicate (zircon) without the intermediate production of zirconium oxide.

This report describes the method of synthesis and some of the results of that synthesis.

44456 See Refractory Metals.

44480 EVALUATION OF CERAMICS FOR CERAMIC TO METAL SEALS. J. A. Zollman and M. Berg, Radio Corporation of America, Lancaster, Pennsylvania. Paper presented at the Sixty-Third Meeting of the American Ceramic Society, Toronto, Canada, April 26, 1961
(12 pages, 2 figures, 7 tables)

The value of a test to evaluate the strength of ceramics and ceramic to metal seals is largely dependent on the techniques used in the preparation of the test specimens. A precision-flexure test for ceramics and seals is described. Strain-gage analysis of this test is also discussed. High-alumina ceramics of various compositions and sizes, sapphire of various crystalline direction and finishes, and ceramic to metal seals of various compositions have been evaluated by this test.

Carbon, Graphite

44296 See Coatings.

44427 HIGH-TEMPERATURE AND OXIDATION-RESISTANT MATERIALS. M. V. Sazonova, A. Y. Sitnikova, and A. A. Appen, Aerospace Technical Intelligence Center, Wright-Patterson Air Force Base, Ohio. AID, Report No. 61-74, May 19, 1961; translated from Zhurnal Prikladnoy Khimii, Vol. 34, No. 3, March, 1961, pp. 505-512, AD 257917
(2 pages)

A study made at the Institute of Silicate Chemistry, Academy of Sciences, USSR, on the protection of carbon and graphite materials from oxidation in air at elevated temperatures is reported. The method of protection selected for the investigation consisted of coating the surfaces of the materials to be protected with mineral enamels. The enamels tested were composed of a high-refractory powdered material cemented together and bonded to the carbon surface by a glasslike binder melted directly on the specimen. Molybdenum silicide or silicon carbide, either alone or in combination, were tested with four different binders. The composition of the binders is given in the article.

44490 See Refractory Metals.

Special Refractories

44378 THERMAL PROPERTIES OF REFRACTORY MATERIALS. J. A. Cape and R. E. Taylor, North American Aviation, Inc., Atomics International, Canoga Park, California. USAF, WADD, TR 60-581, Part II, July, 1961, Contract No. AF 33(616)-6749
(8 references, 22 pages, 13 figures, 3 tables)

Refinements in the transient-thermal-property apparatus are described. With these modifications, the apparatus has been used to determine the thermal diffusivity of tungsten boride from about 1300 to 1600 C. The measured values increase from about 0.054 to 0.058 cm^2/sec over this temperature interval.

The techniques and apparatus for measuring the specific heat of brittle conductors by pulse heating are also described. Resistivity and specific-heat data for uranium silicide of several compositions are reported.

The thermal conductivity of titanium carbide was measured over the temperature region 400 to 1200 C. The steady-state radial heat flow method was used. The results obtained are in marked contrast to values reported in the literature.

44427 See Carbon, Graphite.

44490 See Refractory Metals.

Ceramic Oxide

44481 THERMAL CONDUCTIVITY AND EXPANSION OF BERYLLIA AT HIGH TEMPERATURES. R. E. Taylor, North American Aviation, Inc., Atomics International, Canoga Park, California. Paper presented at the Sixty-Third Meeting, American Ceramic Society, Toronto, Ontario, Canada, April 24, 1961 (7 references, 12 pages, 9 figures, 2 tables)

The thermal conductivities of several specimens of BeO were measured from 350 to 2000 C and found to follow exactly the 1/T relationship to 1700 C, where several competing phenomena occur. One of these phenomena is associated with grain growth. Another questions the validity of the 1/T law at temperatures where the mean free path approaches interatomic distances. Thermal expansions of hot-pressed and isostatically pressed BeO varying from 50 to 99 per cent density were measured from 20 to 2200 C. Decrepitation occurs at 2070 C.

REFRACTORY METALS

44206 See High-Strength Alloys.

44214 See High-Strength Alloys.

44296 See Coatings.

44456 MEASUREMENT OF THERMAL PROPERTIES AT HIGH TEMPERATURES. W. K. Smith, U. S. Naval Ordnance Test Station, China Lake, California. NOTS, TP 2624, Technical Article 13, August, 1961
(4 references, 10 pages, 8 figures, 3 tables)

There are few data available in the literature on the thermal diffusivity and conductivity of many new materials. Conventional methods of gathering such data have proved both tedious and time consuming.

This article describes a method of obtaining data rapidly and with engineering accuracy by the use of a radiant-heating apparatus. It has been possible to make a double sandwich consisting of outer plates of a material of known thermal properties and inner plates of the test material and, by use of a radiant-heating apparatus, to determine, simultaneously, the thermal diffusivity, volume specific heat, and thermal conductivity of the inner test plates versus the temperature.

44463 REFRACTORY METAL SHEET FOR CHEMICAL ROCKETS. R. A. Perkins, Lockheed Aircraft Corporation, Sunnyvale, California. Paper prepared for High-Temperature Materials Working Group Meeting, October 4, 1961, Code 6-90-61-71
(12 references, 37 pages, 5 figures, 9 tables)

The paper reviews the general subject of fabrication of refractory metal components in sheet form for rocket motors.

Significant requirements for fabricated columbium, molybdenum, tantalum, and tungsten unalloyed and alloy sheet are developing in the design and manufacture of liquid- and solid-propellant rocket engines. The following factors will control the rate of progress in the application of these materials to advanced propulsion systems and are considered in this paper: materials requirements, materials capabilities, and fabrication capabilities.

44490 DEVELOPMENT OF METHODS AND INSTRUMENTS FOR MECHANICAL EVALUATION OF REFRACTORY MATERIALS AT VERY HIGH TEMPERATURES. D. H. Fisher, D. N. Gideon, G. M. McClure, and F. C. Holden, Battelle Memorial Institute, Columbus, Ohio. USAF, TR 61-74, Final Report, June, 1961, Contract No. AF 33(616)-6155
(6 references, 59 pages, 30 figures, 9 tables)

A system has been developed for determining the conventional mechanical properties of materials at temperatures up to 4000 F in

4490 (Continued)

vacuum. Techniques for obtaining stress-strain properties in tension and compression are described in the report. Strains are measured optically directly at the gage section to an accuracy of ±50 microinches per inch in a 2-inch gage section. An evaluation of the system was made using a Mo-0.5Ti bar material. Exploratory work was conducted on graphite and a refractory sheet metal. The results of these tests are included in the report.

With the objective of developing a temperature source for use above 4000 F, experiments were conducted to produce and to evaluate tantalum carbide-coated graphite heaters. Good coatings of tantalum carbide were produced both on thin-wall cylindrical heaters and on spiral heaters. It was found that carbon contamination of the atmosphere occurred such that tungsten shields or tungsten specimens were attacked at temperatures under 5400 F. Possible means of improving carbide coatings are suggested.

Columbium

44325 OXIDATION BEHAVIOR OF REFRACTORY METALS AND ALLOYS. J. W. Semmel, Jr., General Electric Company, Evendale, Ohio. Paper received October, 1961 (98 references, 50 pages, 22 figures, 4 tables)

The high-temperature oxidation of columbium, tantalum, molybdenum, tungsten, chromium, and their alloys is described. Both aspects of oxidation, gas absorption and scaling, are considered.

Columbium and tantalum form nonvolatile oxides below 2500 F, but they scale rapidly and absorb oxygen, which results in their embrittlement. Molybdenum forms a volatile oxide at a rapid rate. Compared to molybdenum, the oxide of tungsten is less volatile, but it also forms rapidly. Chromium is much more resistant to oxidation than the other metals; however, it absorbs nitrogen and is embrittled.

Improved oxidation resistance has been obtained in potentially useful alloys of all the base metals except molybdenum. The oxidation resistance of alloys, however, is still below that required for general purposes. Chromium alloys appear most promising in view of the progress made in decreasing nitrogen absorption and oxidation.

The influence of alloying is described with respect to its effect on reducing scaling by stabilizing more protective inner oxides, forming new oxide phases, and decreasing diffusion through oxide layers. Alloying can also decrease the rate of oxygen diffusion into metals like columbium and tantalum, as well as influence the solubilities of gaseous elements of alloys.

44461 REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF COLUMBIUM AND TANTALUM. E. S. Bartlett and F. F. Schmidt, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 130, October 10, 1961 (10 references, 4 pages)

This memorandum briefly reviews major developments in the technology of columbium and tantalum and their alloys, as reported to DMIC during the period from July through September, 1961.

Tensile properties of the Cb-1Zr alloy at temperatures to 3000 F were reported by Boeing. Material tested was about 10 per cent recrystallized prior to testing and had been worked from commercial vacuum-arc-melted ingot.

Du Pont has announced the commercial availability of two columbium-base alloys in various mill shapes, including sheet and strip. D-14 is a binary Cb-Zr alloy, and D-36 is a ternary Cb-Ti-Zr alloy.

The AMC Manufacturing Methods programs for columbium alloy extrusions, forgings, and sheet have shown progress. In particular, practical direct forging of cast F48 alloy has been demonstrated.

Westinghouse has issued a final report covering alloy development work for the period June, 1958, through March, 1961. Studies in this program were devoted primarily to a laboratory survey of the Ta-W-Hf and Ta-W-Re ternary systems.

Tantalum-alloy development work is continuing at Battelle. Several tantalum-base alloys tested to date exhibit tensile strengths in excess of 15,000 psi at 3000 F.

National Research Corporation has recently drawn the Ta-10W alloy to various wire diameters down to 0.020 inch.

4461 (Continued)

Based on previous studies at Crucible on the development of W-Ta-rich alloys from the W-Ta-Mo-Cb system, six of the most promising alloys, selected for high-temperature strength and extrudability, will be evaluated on a larger scale (1-1/4-inch-diameter ingots).

Excellent-quality sheets of the Ta-10Hf-5W (20 x 5 x 0.050 inch) and Ta-30Cb-7.5V (42 x 6 x 0.040 inch) alloys have been produced by joint efforts of ASD and Battelle.

Wah Chang has completed a state-of-the-art determination under Phase I of the AMC Tantalum Extrusion Program.

AMC recently awarded the contract for the development of techniques for rolling tantalum-alloy sheet to Wah Chang.

4493 MECHANICAL, OXIDATION, AND THERMAL PROPERTY DATA FOR SEVEN REFRACTORY METALS AND THEIR ALLOYS. T. E. Tietz and J. W. Wilson, Lockheed Aircraft Corporation, Sunnyvale, California. USN, Final Report, Code 2-36-61-1, September 15, 1961, Contract No. NOas 60-6119-C (16 references, 290 pages, numerous figures, numerous tables)

This report contains data on the mechanical properties and oxidation resistance of columbium, chromium, molybdenum, rhenium, tantalum, vanadium, and tungsten.

Chromium

44160 CORROSION AND ELECTROCHEMICAL BEHAVIOR OF CHROMIUM-NOBLE METAL ALLOYS. N. D. Greene, C. R. Bishop, and M. Stern, Journal of the Electrochemical Society, Vol. 108, No. 9, September, 1961, pp. 836-841 (28 references, 6 pages, 3 figures, 3 tables)

Alloying chromium with small amounts of platinum, palladium, iridium, rhodium, ruthenium, or osmium markedly improves its corrosion resistance to nonoxidizing acids such as sulfuric or hydrochloric acid. The presence of rhodium, palladium, or osmium has little influence on the resistance of chromium to an oxidizing acid such as nitric acid, while platinum, iridium, or ruthenium greatly increases corrosion rates in this medium. These phenomena can be explained in terms of the electrochemical and corrosion behavior of the metals involved and are related to the passive and transpassive behavior exhibited by chromium.

44301 See Engineering Steels.

44325 See Columbium.

44493 See Columbium.

Molybdenum

44325 See Columbium.

44368 REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF MOLYBDENUM AND MOLYBDENUM-BASE ALLOYS. J. A. Houck, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 129, October 6, 1961
(6 references, 3 pages)

This memorandum is a brief review of new developments in the metallurgy of molybdenum and molybdenum-base alloys. The information selected was taken from literature that became available to DMIC during the period from June 30 to September 30, 1961.

The Oregon Metallurgical Corporation reports the production, by reducing molybdenum sulfide with tin, of exceptionally high-purity molybdenum with room-temperature ductility in the as-cast condition.

The Wah Chang Corporation reports that problems encountered in electron-beam melting of calcium reduced molybdenum have been overcome by improving the starting material and the melting techniques.

Universal-Cyclops reports that Phase I (evaluation of melting techniques and primary and secondary fabrication variables for the Mo-0.5Ti and TZM alloys) of their sheet-rolling program for the Bureau of Naval Weapons is nearing completion.

Significant increases in high-temperature tensile and creep-rupture strengths of the arc-cast Mo-0.5Ti-0.08Zr alloy have been reported by Westinghouse Electric Corporation.

The Climax Molybdenum Company reports difficulty in preparing a complex alloy based on 75Mo-25W and 50Mo-50W by the vacuum-arc-casting process. Arc-melted ingots of these compositions consistently cracked during solidification and cooling.

In evaluations of molybdenum sheet materials at Southern Research Institute the Mo-0.5Ti and Mo-0.5-0.08Zr (TZM alloys) had a transition temperature at 65 F. The transition temperature for unalloyed molybdenum was 150 F. In the investigation of tensile and crack-propagation properties of these materials, strain aging appeared to have little effect on unalloyed molybdenum and the Mo-0.5Ti alloy in the room-temperature to 1000 F range. The TZM alloy, however, showed a marked effect in the tensile properties at 1000 F which was attributable to strain-aging phenomena.

44464 DEVELOPMENT AND PRODUCTION OF IMPROVED MOLYBDENUM SHEET BY POWDER METALLURGY TECHNIQUES. C. Wurms and R. Steinitz, Sylvania Electric Products, Inc., Towanda, Pennsylvania. USN, Final Report, March 31, 1961, Contract No. NOas 60-6018-C
(99 pages, 37 figures, 14 tables)

A feasibility study of producing thin molybdenum sheet by powder rolling was performed, as part of a more comprehensive investigation on the production of improved molybdenum sheet by powder-metallurgy techniques.

Green sheet of 40-45-mil thickness could readily be produced by powder rolling, using the equipment available. The green sheet was then sintered, compacted to full density by hot rolling, and reduced by hot and cold rolling to the final thickness of 10 mils. Process variables and their effect on properties were studied.

44464 (Continued)

Properties of the final sheet of 10-mil thickness were determined; the strength and elongation values lie above the tentative specifications of ASTM for sheet material with a thickness below 20 mils. However, in a comparison study with standard powder-metallurgically-produced sheet of similar grain structure and amount of working, the powder-rolled material showed a lower ductility. This could possibly be attributed to a high oxygen content, but further work is necessary for an answer to this problem.

Recommendations and tentative specifications for the selection of powder raw materials and processing procedures have been written. The possibility of a scale-up of the process for wider and heavier sheet is discussed and an estimate of the necessary man-hours to produce 10 pounds of material is included.

44493 See Columbium.

Rhenium

44493 See Columbium.

Tantalum

44325 See Columbium.

44461 See Columbium.

44493 See Columbium.

Vanadium

44493 See Columbium.

Tungsten

44258 REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF TUNGSTEN. V. D. Barth, Battelle Memorial Institute, Columbus, Ohio. DMIC Memorandum 127, September 22, 1961
(16 references, 7 pages)

This memorandum briefly reviews major developments in the technology of tungsten. With few exceptions, the period covered is from May through August, 1961. Specific subjects covered are: consolidation and fabrication, oxidation and protection, and mechanical properties.

44323 DEVELOPMENT OF HIGH STRENGTH MATERIALS FOR SOLID ROCKET MOTORS. B. E. Kramer, General Electric, Cincinnati, Ohio. USN, Final Report No. R61FPD156, March 1, 1961, Contract No. NOrd 18119
(6 references, 92 pages, 40 figures, 9 tables)

Arc and plasma flame spray equipment were used to spray tungsten and tungsten alloys. Spraying was done in air and in a controlled environment chamber. Subscale rocket nozzles were fabricated and tested.

The plasma (powder) spray process provides a stronger tungsten deposit than does the arc (wire) spray process.

Plasma spraying tungsten in a controlled environment offers strength and purity advantages over spraying in air.

Activated sintering by alloy additions is feasible for improving strength and density of sprayed tungsten.

Sprayed tungsten rocket nozzles functioned satisfactorily for firings at moderate chamber pressures ($\sim$600 psi); at higher pressures erosion was encountered.

44325 See Columbium.

44369 OXIDATION OF REFRACTORY METALS AS A FUNCTION OF PRESSURE, TEMPERATURE AND TIME: TUNGSTEN IN OXYGEN. J. N. Ong, Jr., Ford Motor Company, Aeronutronic, Newport Beach, California. Report, October 2, 1961
(12 references, 11 pages, 7 figures, 1 table)

By regarding the kinetics of oxidation of tungsten as occurring by the consecutive reactions: $W + O_2 \longrightarrow WO_2$, $WO_2 + \frac{1}{2} O_2 \longrightarrow WO_{3(s)}$; $WO_{3(s)} \longrightarrow 1/n(WO_3)_{n(vap)}$ and by expressing the rate in terms of conventional chemical kinetic quantities, it is shown that the results of three investigations may be correlated in the temperature range 500 to 1300 C and pressure range 0.0013 to 20.8 atmospheres of oxygen. A good approximate form for the rate of attack of metallic tungsten above 700 C is shown to have the form: Rate = $d(m/A)dt = 5.89\times10^6 \exp(-12,170/T) P^{1/2}$ mg_W/cm^2hr where T is expressed in °K and P in atmospheres of oxygen.

44493 See Columbium.

MISCELLANEOUS

44162 "ELECTROCAPILLARY" STUDIES ON SOLID METALS. D. N. Staicopolus, Journal of the Electrochemical Society, Vol. 108, No. 9, September, 1961, pp. 900-904
(17 references, 5 pages, 8 figures)

The use of a revolving-cup friction-measuring apparatus has made possible a study of the adsorption/desorption of ionic species on solid metal/solution interfaces, as a function of applied electrical potential. The results of this study reveal similarities between the friction characteristics at solid-metal surfaces and the surface tension of liquid metals under the influence of an applied electrical potential. Specific adsorption and chemisorption of ionic species onto solid-metal surfaces can thus be detected from the specific changes in the friction/potential characteristics.

44203 LUBRICANTS AND BEARING SURFACES. A. F. Menton, Missiles & Space, Vol. 7, No. 9, September, 1961, pp. 14-17, 44
(16 references, 5 pages, 5 figures)

This article is a summary of the current state of lubricant and bearing surface technology.

44259 See Applications.

44261 INFRARED DETECTION OF WELD DEFECTS. R. K. Lewis and J. T. Norton, Advanced Metals Research Corporation, Somerville, Massachusetts. USA, WAL, Final Report No. 550/1-1, June 31, 1961, Contract No. DA-19-020-ORD-5228
(17 pages, 9 figures, 1 table)

In the first phase of the program an electrical analog was used to simulate the surface-temperature distribution in plates containing various types of defects when the plate was subjected to a known temperature gradient. The resulting temperature field patterns were analyzed quantitatively to give temperature differences due to the presence of the defect. This information permits a calculation of the minimum size of detectable defects when the performance of the temperature-sensing device is known.

The second phase of the program involved designing, constructing, and testing a device employing infrared techniques for measuring very small temperature differences in the vicinity of room temperature. This device, a microradiometer, is capable of measuring temperature differences as low as 0.05 C at a temperature level of 50 C. Temperature differences were recorded on metal specimens which revealed the presence of artificially introduced defects.

444287 See Nickel Base.

44431 DYNAMIC WHEEL HARDNESS TESTING...BREAKTHROUGH IN GRINDING TECHNOLOGY. T. W. Black, The Tool and Manufacturing Engineer, Vol. 47, No. 4, October, 1961, pp. 83-86
(4 pages, 4 figures)

With a 45-second check, the performance of a new wheel in service can be readily predicted by using a new dynamic-test method. Developed to provide a reliable method of checking grinding-wheel hardness, the test may cast additional light on the fundamental nature of the grinding process itself.

44462 DEVELOPMENT AND EVALUATION OF INTERNAL INSULATION MATERIALS AT AEROJET-GENERAL CORPORATION. Aerojet-General Corporation, Azusa, California. Report, October 4, 1961
(15 pages, 8 figures, 7 tables)

The performance of an internal insulation material in a solid-propellant motor is affected by the material's physical, chemical, and mechanical properties, by the motor's firing parameters, and by the propellant's flame temperature and the composition of the propellant combustion products. In order to develop insulation materials with improved performance, it is important that the relative effect of the many parameters that determine their insulation performance be established, both theoretically and by experiments. The figures and tables given outline these parameters and their effect.

44545 See Composites.

Coatings

44163 VARIATION OF COMPOSITION WITH THICKNESS IN THIN ELECTRODEPOSITED FILMS OF NICKEL-IRON ALLOYS. G. H. Cockett and E. S. Spencer-Timms, Journal of the Electrochemical Society, Vol. 108, No. 9, September, 1961, pp. 906-908
(5 references, 3 pages, 2 figures)

Thin films (500-2000Å) of magnetic alloys, particularly of the Permalloy type (80 per cent Ni-20 per cent Fe), have been proposed for use as memory elements or other rapid switching devices.

However, the time necessary to establish a steady state in the cathode film may be a substantial proportion of the total deposition time of such thin films even at low current densities. It is to be expected, therefore, that a composition gradient will exist in thin metal films and that, for given conditions of plating, the average composition will differ from that of electroplated coatings of conventional thickness.

Since no information appears to be available on the extent of such composition gradients, the variation of composition with thickness has been determined experimentally.

44296 THE PRODUCTION OF MATERIALS BASED ON GRAPHITE WITH REDUCED PERMEABILITY AND WITH IMPROVED OXIDATION AND EROSION RESISTANCE. Hawker Siddeley Nuclear Power Company, Ltd., London, England. USA, TR 29/1961, Final Report, August, 1961, Contract No. DA-91-591-EUC-1582-01-7127-61
(numerous pages, figures, and tables)

This report describes the further investigation of the deposition of refractory materials within a graphite pore structure, the object being to produce a material with reduced permeability to gas flow and with improved erosion resistance. The graphite used for the investigations was Morgan EY9 having a gas permeability of approximately 1×10^{-2} $cm^2 sec^{-1}$. The impregnation was carried out from the chloride vapors of silicon, titanium, and boron conveyed by various carrier gases. Some time was spent in developing a new apparatus which gave closer control of the conditions of impregnation and improved containment of the chloride vapors together with a larger specimen, which was of greater use for test purposes.

44301 See Engineering Steels.

44490 See Refractory Metals.

44545 See Composites.

Applications

44203 See Miscellaneous.

44259 EXPLORATORY ENVIRONMENTAL TESTS OF SEVERAL HEAT SHIELDS. G. P. Goodman and J. Betts, Jr., Langley Research Center, Langley Field, Virginia. NASA, TN D-897, September, 1961
(8 references, 54 pages, 28 figures, 4 tables)

Exploratory tests have been conducted with several conceptual radiative heat shields of composite construction. Measured transient temperature distributions were obtained for a graphite heat shield without insulation and with three types of insulating materials, and for a metal multipost heat shield, at surface temperatures of approximately 2,000 F and 1,450 F, respectively, by use of a radiant-heat facility. The graphite configurations suffered loss of surface material under repeated irradiation. Temperature distribution calculated for the metal heat shield by a numerical procedure was in good agreement with measured data.

Environmental survival tests of the graphite heat shield without insulation, an insulated multipost heat shield, and a stainless-steel-tile heat shield were made at temperatures of 2,000 F and dynamic pressures of approximately 6,000 lb/sq ft, provided by an ethylene-heated jet operating at a Mach number of 2.0 and sea-level conditions. The graphite heat shield survived the simulated aerodynamic heating and pressure loading.

44305 THERMOCOUPLE ALLOY FOR 5000 F. Materials in Design Engineering, Vol. 54, No. 3, September, 1961, p. 13
(1 page)

Temperatures up to 5000 F can now be measured with thermocouples using newly available tungsten-25 per cent rhenium alloy wire. The high-strength alloy retains room-temperature ductility after heating to temperatures as high as 3600 F.

Just announced by Chase Brass & Copper Company, the tungsten-25 per cent rhenium alloy is now in commercial production.

44323 See Tungsten.

44446 See Engineering Steels.

44462 See Miscellaneous.

44463 See Refractory Metals.

44475 APPLICATION OF STATIC-TEST VIBRATION DATA. M. Trummel, California Institute of Technology, Pasadena, California. NASA, TR 32-152, August 20, 1961, Contract No. NASw-6
(4 references, 15 pages, 8 figures, 3 tables)

Vibration data taken during the static testing of solid-propellant rocket motors are significantly affected by factors peculiar to the

4475 (Continued)

test conditions. The results of a small test program are used to illustrate some of the problems involved in applying this data to: (1) predict the flight vibration environment of a payload using the motor, and (2) detect the presence of "oscillatory" burning. It is shown that the greatest source of error is from vibration introduced by the intense acoustic field generated during the firing. The use of an acoustic enclosure to reduce this component of vibration and the use of a soft test stand to reduce the effect of test-stand resonances are discussed. Methods of physical interpretation of the data for use in practical applications are presented.

4488 See Nickel Base.

4529 See Titanium.

4530 See Titanium.

Composites

44171 A STUDY OF THE MECHANISM OF ABLATION OF REINFORCED PLASTICS. D. L. Chamberlain, Jr., D. E. Van Sicle, and C. W. Marynowski, Stanford Research Institute, Stanford, California. WADD, TR 59-668, Part II, February, 1961, Contract No. AF 33(616)-5964, AD 256558L
(4 references, 33 pages, 4 figures, 9 tables)

Nonreinforced polyethylene, poly (methyl methacrylate)(Lucite), Teflon, and pnenolic resins were subjected to r-f discharges produced in nitrogen, oxygen, and air atmospheres. The gaseous products of degradation were determined, and possible mechanisms of attack are discussed.

Analyses of gaseous products resulting from arc-image furnace exposures on selected reinforced resins are reported.

A technique for sampling the gaseous boundary layer of an ablating resin in an argon-stabilized plasma jet is described and results are discussed. Boundary-layer emission spectra, both line and band, are reported for plasma jet exposures of reinforced resins as a function of both viewing position and period of exposure.

44204 AlSiMg CERAMICS CHART NO. 611. American Lava Corporation, Subsidiary of Minnesota Mining and Manufacturing Company, Chattanooga, Tennessee. Received September, 1961, trade literature
(6 pages)

This chart gives mechanical and electrical properties of AlSiMg ceramics.

44214 See High-Strength Alloys.

44472 ON THE CONSEQUENCES OF "A MODEL FOR THE EFFECT OF THICKNESS ON FRACTURE TOUGHNESS" AS APPLIED TO LAMINATED STRUCTURES. J. I. Bluhm, Watertown Arsenal Laboratories, Watertown, Massachusetts. WAL, TR 834.2/6, August, 1961
(6 references, 11 pages, 4 figures)

A model previously suggested for predicting the fracture behavior of thin sheet is extended to cover laminated composites. Thus extended, this model leads to a prediction of the behavior of laminated Charpy bars which is at least qualitatively substantiated by the observed behavior.

44480 See Nonmetallics.

44510 See Beryllium.

44545 REINFORCED, REFRACTORY, THERMALLY INSULATING COATINGS. E. W. Blocker, C. Kallup, S. V. Castner, and S. Sklarew, The Marquardt Corporation, Van Nuys, California. Society of Automotive Engineers Paper No. 417D presented at the National Aeronautic & Space Engineering & Manufacturing Meeting, Los Angeles, California, October 13, 1961
(2 references, 6 pages, 9 figures, 2 tables)