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**BIBLIOGRAPHY WITH ABSTRACTS ON
CARBON-CARBON AND ASSOCIATED COMPOSITES**

F. M. O'Hara, Jr., and J. L. Cook

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BIBLIOGRAPHY WITH ABSTRACTS ON CARBON-CARBON
AND ASSOCIATED COMPOSITES

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OCTOBER 1970

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Foreword

This bibliography comprises the results of a search of *Scientific and Technical Aerospace Reports* and *International Aerospace Abstracts* for the period 1965 to July 1970. The terms searched under were ablation, ablative material, ablative nose cones, carbon, composite materials, composite structures, graphite, heat shielding, nose cones, reentry shielding, reentry vehicles, and rocket nose cones. Literature on carbon-carbon, carbon-graphite, and graphite-graphite composites was sought primarily, but literature on metal-matrix/carbon-reinforced composites and metallic-carbide composites with either a carbon, graphite, or metal matrix were noted, also. These have been grouped under the headings "Carbon-Carbon Composites," "Metallic-Carbide Composites," and "Metal-Matrix Composites." No interest was taken in any composites incorporating glass or plastics.

The entries are arranged according to index number assigned by the source in which the abstract was found: *IAA* ("A" numbers) and *STAR* ("N" numbers). Reference to and verification of these sources can be made through these index numbers. Some abstracts were used from the Defense Ceramic Information Center's *Ceramic Awareness Bulletin*; these appear under the subheading "From CAB." Entries for which abstracts were found in none of these sources appear under "Other."

This bibliography leans on several others. The works of Hanby on metal-matrix composites and of Bower on general fiber-reinforced composites fall into this category. Where such bibliographies already exist, they are listed in this bibliography, and the subject areas and time periods they cover are neglected here.

There is a companion piece to this volume; it covers the literature that is classified or has limitations on its distribution.

Carbon-Carbon Composites

From IAA

A65-23320 *

FIBER-BASE GRAPHITES.

Leonard L. France and Victor Kachur (Westinghouse Electric Corp., Astronuclear Laboratory, Pittsburgh, Pa.).

IN: AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, STRUCTURES AND MATERIALS CONFERENCE, 6TH, PALM SPRINGS, CALIF., APRIL 5-7, 1965. [A65-23300 13-32] New York, American Institute of Aeronautics and Astronautics, 1965, p. 204-211. 6 refs.

AEC-NASA Contract No. NP-1.

Examination of semicommercial fiber-base graphites, including graphitized laminated composites, as potential structural materials for sustained applications to 6000°F. These graphites consist of graphitized cloth or fibers bonded together with the residue from polymer resin binders; they are analogous to the carbonaceous composites intended for ablative applications, except that all volatiles have been removed during the graphitization treatment. The density of these materials ranges from 0.90 to 1.50 g/cm³. Their mechanical properties are highly directional and dependent upon predominant fiber orientation; the highest tensile strength (over 5000 psi at room temperature) is observed parallel to the fiber direction, while compressive strength is maximum (over 30,000 psi) across the fibers. Electrical and thermal conductivities are also dependent on orientation, being highest along the direction of the fiber. Both strength and conductivities are markedly increased by additional carbonaceous residue from reimpregnation treatments. The fiber-base grades are suitable for rough-molding to hardware shape, while the laminated grades may be worked into tubular hardware configurations.

(Author) M. M.

A66-34618

FIBER-REINFORCED CARBON AND GRAPHITE.

C. W. Rohl and J. H. Robinson (Carborundum Co., Niagara Falls, N.Y.).

Research/Development, vol. 17, July 1966, p. 20-24.

Description of a carbon/graphite form that meets many requirements for carbon and graphite materials. The material, called CARB-I-TEX, is lightweight, high-strength, uniformly heterogeneous, carbon or graphite material, capable of withstanding high temperatures of 6000°F and up. It is highly resistant to both thermal and mechanical shock, and also resists corrosion and erosion. The material contains no resin-bonded laminates, being of exceptionally high purity. It is not wetted by many molten metals, can be manufactured to furnish many specialized characteristics, and can be formed or machined into a wide variety of shapes.

M. M.

A67-13412 *

MECHANICAL BEHAVIOR OF A CONTINUOUS FILAMENT CARBON COMPOSITE.

L. L. France, V. Kachur, and T. F. Hengstenberg (Westinghouse Electric Corp., Atomic, Defense and Space Group, Astronuclear Laboratory, Pittsburgh, Pa.).

IN: ADVANCED FIBROUS REINFORCED COMPOSITES; SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS, NATIONAL SYMPOSIUM AND EXHIBIT, 10TH, SAN DIEGO, CALIF., NOVEMBER 9-11, 1966, PAPERS. [A67-13399 03-18]

North Hollywood, Calif., Western Periodicals Co. (Science of Advanced Materials and Process Engineering Series, Volume 10), 1966, p. B-81 to B-93. 8 refs.

AEC-NASA-sponsored research.

The mechanical properties of a continuous carbon filament-carbon binder composite fabricated in 0.50-in.-diam rod form and graphitized at approximately 2700°C are presented. The mechanical data described include tensile, compression, flexure, fatigue, and shear properties at 20°C and shear and tensile properties over the temperature range of from 20 to 2500°C. Tensile strength values of approximately 40,000 psi at 20°C have been obtained. The basic mode of failure of most of the tensile and flexural specimen configurations evaluated is that of shear at the filament-binder interface. The limiting shear stress was determined to be approximately 1800 psi at 20°C, and it increased slightly with increasing temperature to about 2000 psi over the temperature range of from 1200 to 2500°C. Conventional light and electron microscopic evaluation of the material structure and its mode of failure are presented and discussed in relation to the components (filament, binder, and the binder-filament interface) of the composite. The material failure mechanism is related to component design and potential applications for material of this type. Present limitations imposed by the behavior of the binder phase and binder-filament interface are discussed in relation to the development of improved composite structures of this type. The utilization of the recently developed high-strength graphite or carbon fibers in graphite composites offers the possibility of substantial improvement in mechanical properties, provided the binder and interface strength can be improved.

(Author)

A67-18320 *

THERMAL PERFORMANCE OF AN ADVANCED RADIATION COOLED HEAT SHIELD SYSTEM.

J. K. Haviland (LTV Aerospace Corp., Missiles and Space Div., Structures and Materials Section, Dallas, Tex.) and J. E. Medford (LTV Aerospace Corp., Missiles and Space Div., Dallas, Tex.).

American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 5th, New York, N.Y., Jan. 23-26, 1967, Paper 67-153. 13 p. 11 refs.

Members, \$0.75; nonmembers, \$1.50.

An extension to the classical radiation cooled reentry heat shield concept is introduced, in which the external surface is permitted to recede. Analytical results are presented which show that if such a heat shield system consists of a graphite surface material over graphite felt insulation, then it performs efficiently over a wide range of applied heat loads. Experimental data are presented on surface recession rates for graphitic materials, and they are correlated on the basis of diffusion controlled oxidation at

moderate heat loads, and surface spalling at extreme heat loads. Comparative analytical results obtained on a high-speed digital computer are presented which indicate that the radiation cooled system is lighter than a low-density charring ablator for almost the entire range of entry conditions. The difference is most pronounced at low heat loads and long reentry times where weight required for insulation is most important. Weights as low as one-fourth of those required for the charring ablator were computed for such conditions.

(Author)

A67-41913

DENSIFIED CARBON AND GRAPHITE.

A. R. Ford.

The Engineer, vol. 224, Oct. 6, 1967, p. 454-456.

Discussion of three methods for the production of densified carbon and graphite. The three methods of overcoming porosity involve the use of new forms of carbon, resin and metal impregnation, and carbon impregnation with carbon. Improvements attained by using these methods in the production of glass-to-metal sealing jigs and in the field of high-temperature metallurgy are examined.

R. B. S.

A68-15000

NEW CARBON REINFORCEMENTS OFFER BETTER PERFORMANCE.

Dale M. Dossier (Minnesota Mining and Manufacturing Co., St. Paul, Minn.).

Space/Aeronautics, vol. 46, Nov. 1967, p. 103, 104, 106, 109, 110.

Development of a new family of special carbonaceous fibers and fibrous fabrics to satisfy the continuing demand for stable and erosion- and heat-resistant materials for ablative aerospace structures. Tradenamed "Pluton," these materials have carbon structures modified by the inclusion of boron, phosphorus, nitrogen, and other elements. They are chemically inert, have excellent heat resistance, and can be made electrically conductive or non-conductive, as desired. Screening tests for ablatives fully confirmed the performance advantages of Pluton-reinforced composites. The major limitation of Pluton materials is their susceptibility to oxidation, which restricts them in long-term high-temperature applications.

M. F.

A68-24253

PLASMA ARC TESTING OF HYPERVELOCITY MATERIALS.

Ernst M. Goldstein (Martin Marietta Corp., Aerospace Group, Denver, Colo.).

American Institute of Aeronautics and Astronautics, and American Society of Mechanical Engineers, Structures, Structural Dynamics and Materials Conference, 9th, Palm Springs, Calif., Apr. 1-3, 1968, AIAA Paper 68-298, 3 p. 5 refs.

Members, \$1.00; nonmembers, \$1.50.

Study of recession and weight loss of graphites and graphite composites in plasma arc tests with simulated air at low and high heat fluxes. It is concluded that the many chemical and physical reactions occurring during the high-temperature ablation of graphite composites could be the reason for their poor performance as opposed to pure graphite whose high-temperature ablation is diffusion controlled and not temperature dependent.

R. B. S.

A68-30319

THREE-Dimensionally FIBER REINFORCED GRAPHITE COMPOSITES.

J. W. Herrick, R. W. King, R. M. Lurie, L. E. McAllister, and R. J. McHenry (Avco Corp., Avco Missiles, Space and Electronics Group, Avco Space Systems Div., Lowell, Mass.).

American Institute of Chemical Engineers, Materials Conference, Symposium on Plastics - High Temperature Polymers, Part 2, Philadelphia, Pa., Mar. 31-Apr. 4, 1968, Paper 33 D, 14 p. 5 refs. \$0.50.

Description of initial work on the preparation and evaluation of 3-D graphite consisting of graphite fibers oriented in three directions in a graphite matrix. Preliminary tests indicate that this ma-

terial possesses excellent mechanical strengths and both mechanical and thermal shock resistance. It is much stronger than bulk graphite and, when all directions are considered, is superior to commercially available unidirectional fiber-reinforced graphite. Problems of interlaminar shear strength are greatly reduced with 3-D graphite. The unique nature of 3-D weaving makes it possible to prepare structural graphite with properties adjusted to meet the requirements of the material designer. Recent process developments now permit the fabrication of both solid-block and cylindrical 3-D parts.

M. M.

A69-22071

WHERE GRAPHITE SERVES.

Roger Bacon (Union Carbide Corp., Carbon Products Div., Parma Technical Center, Parma, Ohio).

Metal Progress, vol. 95, Mar. 1969, p. 116, 118, 120, 124.

Description of the tensile strengths and moduli of elasticity of several commercially available stiff graphite fibers. The fibers are produced starting from a thread of an organic textile (usually rayon or polyacrylonitrile), which is then carbonized in a series of heating steps until the carbon content reaches 85 to 100%. The use of the graphite fibers in high-performance composites and ablative materials, and in fiber-reinforced materials with good ablation behavior, is discussed.

M. G.

A69-26807

AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS AND AMERICAN SOCIETY OF MECHANICAL ENGINEERS, STRUCTURES, STRUCTURAL DYNAMICS AND MATERIALS CONFERENCE, 10TH, NEW ORLEANS, LA., APRIL 14-16, 1969, PROCEEDINGS. New York, American Society of Mechanical Engineers, 1969. 477 p. Members, \$15.; nonmembers, \$22.

A69-26845

RELIABILITY OF ANALYSIS TECHNIQUES AND SENSITIVITY TO MATERIAL PROPERTIES.

J. C. Schutzler and H. W. Babel (McDonnell Douglas Corp., McDonnell Douglas Astronautics Co., Western Div., Santa Monica, Calif.).

IN: AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS AND AMERICAN SOCIETY OF MECHANICAL ENGINEERS, STRUCTURES, STRUCTURAL DYNAMICS AND MATERIALS CONFERENCE, 10TH, NEW ORLEANS, LA., APRIL 14-16, 1969, PROCEEDINGS. [A69-26807 12-32]

New York, American Society of Mechanical Engineers, 1969, p. 422-428. 14 refs.

Research supported by the McDonnell Douglas Independent Research and Development Program.

Study of three complementary approaches to the improvement of graphite for high-temperature application. The approaches involve improved thermal stress analysis techniques, parametric sensitivity studies for guidance in the selection and production of superior graphite grades, and screening tests for identifying defective material. The key items in the advancement of current technology are (1) the availability of a general analytical model and associated computer programs that account for the nonlinear behavior of graphite in addition to anisotropy and temperature-dependent properties, (2) the development of a valid failure criterion, and (3) improvement in nondestructive and destructive tests for screening out defective billets. It is shown that significant improvements can be made in the ability to predict the performance of graphite components by the application of the above techniques.

(Author)

A69-26847

SOME DYNAMIC MECHANICAL PROPERTIES OF DISTENDED CARBONS.

L. M. Lee, R. P. May, and T. R. Guess (Sandia Corp., Sandia Laboratory, Solid Dynamics Research Dept., Albuquerque, N. Mex.).

IN: AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS AND AMERICAN SOCIETY OF MECHANICAL ENGINEERS, STRUCTURES, STRUCTURAL DYNAMICS AND MATERIALS CONFERENCE, 10TH, NEW ORLEANS, LA., APRIL 14-16, 1969, PROCEEDINGS. [A69-26807 12-32]

New York, American Society of Mechanical Engineers, 1969, p. 418-452. 27 refs.

AEC-supported research.

Results of an experimental study performed to define the dynamic response of seven distended carbon materials to shock loading. The study has included measurement of equation of state parameters to 235 kb, unloading behavior, and spallation strengths. The response to shock loading in the low-stress (partially compacted) region was found to be dependent on the initial structure of the material, while in the high stress region the response was primarily affected by the initial density. The Hugoniot data were fitted to an empirical model previously proposed to describe the response of partially compacted porous materials. The results of the unloading wave experiments and attenuation data indicated that the unloading behavior of these materials cannot be suitably described by either hydrodynamic or solid unloading approximations in the partially compacted region. The spallation results show the relative dynamic tensile strengths for the distended carbons and the strengthening effect of reinforcing the filament materials in the third direction. (Author)

A69-35519

ADVANCES IN FIBER REINFORCED CARBON AND GRAPHITE.

Allen P. Penton and W. M. Fassell (Philco-Ford Corp., Aeronutronic Div., Newport Beach, Calif.).

IN: MATERIALS AND PROCESSES FOR THE 70'S; SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS, NATIONAL SYMPOSIUM AND EXHIBITION, 15TH, LOS ANGELES, CALIF., APRIL 29-MAY 1, 1969, PROCEEDINGS. (A69-35501 19-15)

North Hollywood, Western Periodicals Co.; Azusa, Calif., Society of Aerospace Material and Process Engineers (Science of Advanced Materials and Process Engineering Proceedings, Volume 15), 1969, p. 229-237.

Review of significant advances made in fiber reinforced pyrolyzed plastics in the past two years. These advances have included improved processing techniques and methods of precisely controlling density. Composites with new reinforcing materials, such as three-dimensional woven quartz and high-modulus graphite fibers, display some outstanding combinations of engineering properties. Progress has resulted in demanding areas of application such as advanced reentry systems, advanced propulsion systems, and high-temperature gas turbines. (Author)

A69-35539

PYROLYTIC GRAPHITE COATED COMPOSITE MATERIALS.

E. L. Olcott (Atlantic Research Corp., Materials Dept., Alexandria, Va.) and D. R. Zorich (USAF, Rocket Propulsion Laboratory, Solid Rocket Div., Edwards AFB, Calif.).

IN: MATERIALS AND PROCESSES FOR THE 70'S; SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS, NATIONAL SYMPOSIUM AND EXHIBITION, 15TH, LOS ANGELES, CALIF., APRIL 29-MAY 1, 1969, PROCEEDINGS. (A69-35501 19-15)

North Hollywood, Western Periodicals Co.; Azusa, Calif., Society of Aerospace Material and Process Engineers (Science of Advanced Materials and Process Engineering Proceedings, Volume 15), 1969, p. 455-462, 11 refs.

Pyrolytic graphite until recently has been utilized for propulsion components in an edge-oriented, washer configuration or as a free-standing shape. A more promising configuration is as a coating deposited on a compatible graphite substrate material. Pyrolytic graphite-coated composite materials have proved to be an excellent nozzle throat material for advanced solid-propellant motors utilizing high energy, metallized propellants. (Author)

A69-36320

HIGH-TEMPERATURE MATERIALS.

Murray A. Schwartz (ITT Research Institute, Ceramics Div., Chicago, Ill.).

Space/Aeronautics, vol. 52, July 1969, p. 95-98, 102, 108, 116, 117, 15 refs.

Discussion of various types of high-temperature materials for aerospace and spacecraft applications. The carbon-carbon composites appear attractive for reentry nose cones because of their high thermal shock resistance, for turbine vanes and buckets because of their high

strength-to-density ratio, for rocket nozzles because of their ease of fabrication, and for a wide variety of other applications because they can be tailored. Radomes, optical windows, and nonballistic reentry leading edges have been the principal applications for oxides and their composites. Carbide composites and graphite developments are considered. Ablative systems are based on polymers that decompose, melt, and vaporize, thus absorbing heat and keeping the subsurface cool. Applications of fibers are considered, and high-temperature metals and coatings are discussed. G.R.

A69-38671

FABRICATION OF GRAPHITE FIBER-REINFORCED GRAPHITE COMPOSITES.

J. L. Cook and F. Lambdin (Union Carbide Corp., Nuclear Div., Oak Ridge, Tenn.).

American Society for Metals and American Society of Tool and Manufacturing Engineers, Western Metal and Tool Conference and Exposition, Los Angeles, Calif., Mar. 10-13, 1969, ASM Technical Paper W 9-20-4, 13 p.

Members, \$1.50; nonmembers, \$3.00.

Composites consisting of graphite fibers and either a thermoplastic or thermosetting resin were spray formed onto graphite mandrels, carbonized to 1000 deg C, and densified as desired by repeated resin impregnation-carbonization cycles. Sections up to one inch in thickness and ranging in density from 0.2 to 1.7 gram per cu cm have been fabricated using spraying as the basic fabrication method. Isostatic and match-die compaction were used to increase the fiber population. Preliminary physical and mechanical properties of these composite materials were evaluated. (Author)

A70-12713

MATERIALS REINFORCED BY FIBRES.

R. J. Lumby (Joseph Lucas, Ltd., Group Research Centre, Burnley, Lancs., England).

IN: NEWER ENGINEERING MATERIALS. (A70-12709 02-17)

Edited by R. F. Winters.

London, Macmillan and Co., Ltd., 1969, p. 67-83, 17 refs.

Review of fiber-reinforced composite materials, their fabrication, properties, and applications. The importance of fiber-reinforced composite materials for various industrial uses is indicated, and the general characteristics of composites consisting of different types of fibers and matrices are described. Equations for calculating the modulus of elasticity and the tensile strength of fiber composites are presented. Different types of bonding of matrix and fibers are reviewed and discussed. Particular attention is given to a detailed survey of the properties of different fiber materials and fiber composites grouped according to use at different temperatures.

A70-13618

SOME APPLICATIONS OF CARBONS AND GRAPHITES IN SPACE TECHNOLOGY.

A. C. Parmee (Ministry of Technology, Rocket Propulsion Establishment, Westcott, Bucks., England).

(British Interplanetary Society, Symposium on Materials in Space Technology, 3rd, University of Bristol, Bristol, England, Apr. 10, 11, 1969, Paper.)

British Interplanetary Society, Journal, vol. 22, Dec. 1969, p. 393-401, 21 refs.

(For abstract see issue 23, page 4135, Accession no. A69-42160)

A70-13619

CHEMICAL EROSION OF GRAPHITE ROCKET NOZZLES.

G. A. Heath and R. W. Thackray (Ministry of Technology, Rocket Propulsion Establishment, Westcott, Bucks., England).

(British Interplanetary Society, Symposium on Materials in Space Technology, 3rd, University of Bristol, Bristol, England, Apr. 10, 11, 1969, Paper.)

British Interplanetary Society, Journal, vol. 22, Dec. 1969, p. 402-410, 8 refs.

(For abstract see issue 23, page 4180, Accession no. A69-42156)

A70-16617

ABLATION.

Harry J. Doyle (Grumman Aerospace Corp., Bethpage, N.Y.).

IN. HANDBOOK OF FIBERGLASS AND ADVANCED PLASTICS COMPOSITES. (A70-16601 05-18)

Edited by George Lubin.

New York, Van Nostrand Reinhold Co., 1969, p. 540-551.

Detailed description of the mechanisms and applications of ablative cooling. Salient points of the heat transfer mechanism in albedo which are relevant to data requirements are outlined. Applications of ablation systems to ballistic nose cones and the Apollo spacecraft are discussed, together with the desired properties for an optimum material system in ablating environments, the effects of the thermal environment on the performance of ablation materials, pyrolyzed and graphitized plastics, and modified phenolic ablators. M.M.

A70-18147 #

SOME OBSERVATIONS ON THE INFLUENCE OF GRAPHITE MICROSTRUCTURE ON ABLATION PERFORMANCE.

D. F. McVey, I. Auerbach, and D. D. McBride (Sandia Laboratories, Albuquerque, N. Mex.).

American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 8th, New York, N.Y., Jan. 19-21, 1970, Paper 70-155. 21 p. 26 refs.

Members, \$1.00; nonmembers, \$1.50.

AEC-supported research.

It has traditionally been assumed in ablation calculations that graphite acts as a structurally homogeneous material in that it consists of a single chemical element: carbon. Comparisons of ablation computations based on this assumption with experimental data have revealed discrepancies, particularly at the more severe environmental conditions. Not only are discrepancies in mass recession data noted between experiment and theory, but also differences between different graphites tested under the same conditions. This paper describes a study in which several graphite materials were tested in arc heaters at different stagnation pressure and enthalpy conditions. Pre- and posttest examinations of the material surface and internal structures were made by radiography, mercury and Quantimet porosimetry, helium permeability, electron scanning and optical microscopy, X-ray diffraction, and surface roughness analysis. The microstructural data, along with the relative ablation performance were used to show the correlation between microstructure and ablation performance. The major influences are grain size, porosity, and degree of graphitization. The ablation mechanism involves enhanced removal of binder material with resultant grain exposure and subsequent removal of particulate matter. The observations were then used to propose a particulate ablation model based on the concept of a critical roughness. (Author)

A70-22758

Carbon fibre—A question of structure.

Dwarakanath V. Badami (Turner Brothers Asbestos Co., Ltd., Rochdale, Lancs., England). *New Scientist*, vol. 45, Feb. 5, 1970, p. 251-255.

Discussion of the fabrication, properties and prospects of the carbon fibres. The structure and properties of graphitizing and nongraphitizing carbons are discussed. The principles of the fabrication process of carbon fibres invented by Watt, Phillips and Johnson are outlined. Properties of the carbon fibres and carbon-fibre reinforced composites are briefly reviewed. Z.W.

A70-26672

A new glassy carbon fibre. K. Kawamura and

G. M. Jenkins (Swansea, University College, Swansea, Wales). *Journal of Materials Science*, vol. 5, Mar. 1970, p. 262-267. 9 refs. Research sponsored by the National Coal Board.

It is shown that phenol-hexamine polymers may be extruded from the melt to produce fibers which may be carbonized to form fine high-strength glassy carbon fibers with a tensile strength of up to 300,000 lb/sq in. after 900 C heat-treatment. The fibers have a specific modulus of about 5 Mm compared with about 14 Mm for carbonized polyacrylonitrile fibers and about 3 Mm for silica glass

fibers. Both strength and modulus increase rapidly with decrease in diameter. The fibers are subjected to no special surface treatment after extrusion, but electron microscopy indicates the presence of a thin textured sheath surrounding a true glassy carbon core in the final fiber. The fibers have the advantages of glassy carbon (inertness to chemical attack, resistance to abrasion) and give promise of a new range of cheap high-strength carbon fibers derived from coal tar fractions. (Author)

A70-28776

Carbon and graphite composites - Orthog-

onally isotropic wool base versus anisotropic rayon base. D. H. Leeds, D. W. Bauer, A. P. Valeriani, and W. H. Smith (Super Temp Co., Santa Fe Springs, Calif.). *SAMPE Journal*, vol. 6, Apr.-May 1970, p. 35-44. 26 refs.

Description of the preparation and properties of wool felt-based carbon and graphite composite materials developed specifically for orthogonally isotropic high-shear strength. The method of manufacture of carbon-carbon, carbon-graphite, and graphite-graphite composites from raw wool felt precursors and rayon felt precursors is briefly explained. An extensive experimental program was carried out to examine both the macrostructure and microstructure, and the mechanical and thermal properties of these composites. The experiments included the determination of the effect of temperature on linear shrinkage and weight loss during carbonization, ultimate tensile, flexure, and compressive strength, linear thermal expansion, and thermal conductivity. The results obtained for both the wool felt-based and rayon felt-based composites are discussed and compared. It is believed that wool felt-based carbon composites may have more potential for nonorthogonally isotropic high strength uses than is possible with smooth synthetic fiber-based materials. O.H.

A70-29503 #

Combined coatings on graphite (Kombiniro-

vannye pokrytiia na grafit). V. P. Eliutin, V. I. Kostikov, and V. Ia. Levin (Moskovskii Institut Stali i Splavov, Moscow, USSR). *Akademiia Nauk SSSR, Izvestiia, Neorganicheskie Materialy*, vol. 6, Mar. 1970, p. 414-417. 10 refs. In Russian.

Study of protective coatings for graphite, composed of Si-Zr alloys. A study is made of the wettability, kinetics of spreading, and impregnation of graphite with different densities by liquid alloys of the Si-Zr system. It is found that coatings of these alloys when not subjected to subsequent annealing do not have protective properties. Diffusion annealing results in the formation of a combined coating SiC + ZrC + Si(x)Zr(y) on compact graphites, and a carbide coating on porous graphite. Z.W.

From STAR

N65-10352# Union Carbide Corp., Lawrenceburg, Tenn. Advanced Materials Lab.

PYROLYTIC COATING OF CARBON FILAMENTS Quarterly Progress Report, 15 Nov. 1963-15 Feb. 1964

K. J. Zetsch and P. H. Higgs 29 Feb. 1964 26 p

(Contract AF 33(657)-11297)

(AD-447951)

Typical pyrolytic graphite coatings on individual carbon yarn filaments were found to increase the filament tensile strength from 92,000 to 130,000 lb/in.², which corresponds to an improvement of approximately 40%. The same type of coatings increased the thermal conductivity of carbon yarn filaments from 0.064 to 0.145 cal/sec-cm.²°C at room temperature, and from 0.016 to 0.019 cal/sec-cm.²°C at temperatures slightly above 2000°C. Variations in the integral pull strength of uncoated and pyrolytically coated carbon yarn are shown to be random and to follow an essentially normal gaussian pattern. Superposition of pertinent distribution curves is used to

separate scatter from genuine effects of processing. In this fashion, the superiority of coated over uncoated carbon yarn is characterized in statistical terms. Author

N65-14302# Union Carbide Corp., Lawrenceburg, Tenn. Carbon Products Div.

IMPROVED GRAPHITE MATERIALS FOR HIGH-TEMPERATURE AEROSPACE USE Quarterly Progress Report, 1 May-31 Jul. 1964

P. G. Lafyatis et al 15 Aug. '64 114 p refs
(Contract AF 33(657)-11171)
(AD-605942)

Several oxygen-substituted and quinone compounds were found to have extremely high reactivity. X-ray data for graphites prepared from model aromatic hydrocarbons were reevaluated. Complexing agents, p-benzoquinone and SbCl_5 , produce a disordered graphite from aromatic hydrocarbons which otherwise result in highly ordered graphite. Thermal dehydrogenation curves are shown for fluoranthene, p-terphenyl, acenaphthylene, and bifluorenyl. Hydrogen content at 1000°C is related to the structure of the final graphite. Coupling constant assignments were made for the hexamethylbenzene, diazobenzil, and diazofluorene ESR spectra using the SESRS (Simulation of Electron Spin Resonance Spectra) computer program. Electrically conducting blacks seeded material produced a graphite with a markedly lower resistance than that obtained from material seeded with acetylene black. Two pilot-scale coker runs to produce high-thermal-expansion isotropic cokes were made. Author

N65-18875# Union Carbide Corp., Lawrenceburg, Tenn. Advanced Materials Lab.

PYROLYTIC COATING OF CARBON FILAMENTS Final Report, May 15, 1963-May 15, 1964

K. J. Zeitsch and P. H. Higgs Wright-Patterson AFB, Ohio, AF Mater. Lab., Nov. 1964 160 p refs
(Contract AF 33(657)-11297)
(ML-TDR-64-297; AD-608764)

A continuous process has been developed to coat the individual filaments of graphite yarn with pyrolytic graphite. The pyrolytic coating increased the strength-to-weight ratio of the filaments and acted as a sizing on the yarn to make weaving easier. Tapes woven from the coated yarn showed a load distribution factor as high as 0.9. Author

N65-25371# General Electric Co., Philadelphia, Pa. Re-Entry Systems Dept.
EVALUATION OF GRAPHITE COMPOSITES IN RE-ENTRY ENVIRONMENTS Progress Report

E. J. Nolan and R. A. Tanzilli Aug. 1964 14 p
(Contract AF 33(615)-1768)
(PR-1; AD-460964)

Detailed program plans, budgets, and program objectives were formulated and design and fabrication of test specimens initiated. The most recent heat and mass transfer correlations developed by Scala and Gilbert for a blunted-conical body are utilized in the systems study. Author

N65-31827# General Electric Co., Philadelphia, Pa. Reentry Systems Dept.

EVALUATION OF GRAPHITE COMPOSITES IN RE-ENTRY ENVIRONMENTS Progress Report

E. J. Nolan and R. A. Tanzilli Feb. 1965 24 p refs
(Contract AF 33(615)-1768)
(PR-3; AD-463565)

Some preliminary results of the thermodynamic portion of the systems study for a typical ballistic reentry have been obtained on four (4) graphitic material composites. During the third

quarter of this study, the experimental portion of the program, which was concerned with the characterization of the oxidation and sublimation behavior of five (5) graphite composites, was completed. A total of 118 tests have been conducted during this experimental phase. Experimental mass transfer data is shown graphically, and comparisons made with theory. An additional test material designated JTA was introduced into this phase of the program to compare its performance with that of the other graphite composites. Markedly, superior oxidation resistance was observed for JTA at low heating rates apparently due to the formation of protective oxide coatings. At higher heating rates, however, no such advantage is observed. Author

N66-14470# Air Force Systems Command, Wright-Patterson AFB Ohio. Air Force Materials Lab.

FILAMENTOUS CARBON AND GRAPHITE Technical Report, Jul 1964-Mar. 1965

D. L. Schmidt and H. T. Hawkins Aug. 1965 43 p refs
(AFML-TR-160; AD-623517) CFSTI: HC \$2.00/MF \$0.50

Constructive pyrolysis of fibered organic materials yields a corresponding carbon or graphite fibrous product which is flexible, thermally stable, non-melting, strong, lightweight, and chemically inert. These novel fibers have been used as reinforcing agents in structural, ablative, and pyrolyzed plastics, and the composites thereof exhibit a combination of properties not previously obtainable. Recent methods for improving fiber properties are given. These include both vat-dipping and pyrolytic vapor deposition techniques. Property data on improved fibers are also listed. Author (TAB)

N66-21505# Washington Univ., St. Louis, Mo. Dept. of Chemical Engineering

AN INVESTIGATION OF CARBON DEPOSITION Progress Report, 1 Nov. 1965-31 Jan. 1966

Eric Weger 2 Feb. 1966 3 p
(Contract AF 04(694)-695)
(PR-3; AD-627813) CFSTI: HC \$1.00/MF \$0.50

A brief summary is given of research on carbon deposition using an induction furnace. The pore structure characterization is discussed. TAB

N66-22255*# General Electric Co., Philadelphia, Pa.
THE OXIDATION AND SUBLIMATION OF GRAPHITE IN SIMULATED RE-ENTRY ENVIRONMENTS

J. W. Metzger, M. J. Engel, and N. S. Diaconis [1965] 91 p refs Presented at the 18th Ann. Meeting of Heat Transfer and Fluid Mech. Inst., Los Angeles, 21-23 Jun. 1965 (Contracts SNPC-10; AF 04(694)-222)
(NASA-CR-60395) CFSTI: HC \$3.00/MF \$0.75 CSCL 11B

An experimental study of the oxidation and sublimation of two types of graphite in simulated reentry environments is described. The two graphites are ATJ, a fine grain commercial graphite, and pyrolytic graphite, a highly anisotropic material produced by vapor deposition. The experimental program is described, the data analysis techniques used to obtain the various correlations are presented, and the comparison of the results with the theoretical treatments of Scala are shown. R.N.A.

N66-33267# Watervliet Arsenal, N. Y. Benét Labs
EFFECT OF FIBER GEOMETRY ON STRESS IN FIBER-REINFORCED COMPOSITE MATERIALS, PHASE 2

Thomas F. Mac Laughlin Apr. 1966 26 p ref
(WVT-6610; AD-633984) CFSTI: HC \$2.00/MF \$0.50

Six additional two-dimensional photoelastic models of fiber-reinforced composite material configurations were constructed and tested to study the effects on the shear stress distribution in an elastic matrix of (1) a gradually tapered fiber, (2) a fiber whose end was unbonded from the matrix,

and (3) aligned fibers having various gap lengths between fiber ends. The tapered and unbonded fiber ends were found to produce somewhat higher peak stresses in the matrix than fiber end shape models tested in the phase 1 investigation. It made little difference whether the gap between aligned fiber ends was open, simulating a void resulting from a broken fiber, or filled with matrix material. Author (TAB)

N67-10501/ Air Force Systems Command, Wright Patterson AFB, Ohio. Air Force Materials Lab.
GEOMETRICAL EFFECTS OF FILAMENT TWIST ON THE MODULUS AND STRENGTH OF GRAPHITE FIBER REINFORCED COMPOSITES Technical Report, Oct. 1965-Jan. 1966

James M. Whitney May 1966 18 p refs
(AFML-TR-66-131; AD-638299) CFSTI: HC \$1.00/MF \$0.50

Using basic theory previously appearing in the literature, equations are derived for determining the effects of yarn twist on the modulus and strength of graphite reinforced composites. In the strength analysis the variation of individual filament properties is considered. Results show that a few turns of twist per inch have little effect on either modulus or strength. However, these properties decrease in value rapidly beyond seven turns per inch. The theory was checked using data from a unidirectional composite reinforced with graphite yarns having approximately five turns of twist per inch. Since the processability of graphite filaments into a fiber reinforced composite is improved by using a twisted yarn, it seems advantageous from a geometrical standpoint to use yarns containing several turns of twist per inch. Author (TAB)

N68-16912/ Air Force Systems Command, Wright-Patterson AFB, Ohio. Translation [R].
TECHNOLOGY OF CARBON-GRAPHITE MATERIALS [TEKNOLOGIYA UGLEGRAFITOVYKH MATERIALOV]
Ye. F. Chalykh 16 May 1967 296 p refs Transl. into ENGLISH of the book Tekhnologiya Uglegrafitovykh Materialov, Moscow, Gostoptekhnizdat, 1963 p 1-304
(FTD-MT-65-132; AD-663369)

The book presents an outline of the characteristics and properties of carbon-graphite materials. Detailed information is given on the technology of their preparation, the selection of initial materials, their preparation for the composition of industrial recipes, the technology of bulk production, pressing, sintering, graphitizing, impregnation, and packing. Author (TAB)

N68-21183/ Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena
REVIEW OF ADVANCED COMPOSITE MATERIALS FOR SPACECRAFT APPLICATIONS
R. G. Moss 1 Nov. 1967 123 p refs
(Contract NAS7-100)
(NASA-CR-94040; JPL-TM-33-357) CFSTI: HC \$3.00/MF \$0.65 CSCI 110

Information was obtained from the literature, by attendance at meetings and symposia, discussions with workers in the field, and visits to some of the organizations active in composite development. Brief discussions of the theory of composite strengthening and reinforcement mechanics are presented. Advantages, disadvantages, problem areas, and actual and potential applications are described. The status of testing, processing, forming, fabrication, and joining are noted. Many of the more important programs and organizations active in composite development are identified, as are anticipated advances in composite technology. Abstracts and comments on papers and reports on fibers and composites and a 162-title bibliography are included. Author

N68-24581/ United Kingdom Atomic Energy Authority, Harwell (England) Research Group.
FIBROUS FORMS OF CARBON

O. Voller and E. Spork May 1967 21 p refs Transl. into ENGLISH from Ber. Deut. Keram. Ges (Bonn), v. 43, no. 3, 1966 p 199-208

(AERE-TRANS-1079) HMSO 3s

Carbon has been used for some time now in the form of flexible fibres. Originally these carbon felts, cloth, yarns and wools were made exclusively with a cellulose base. Later these materials were replaced by synthetic and animal fibres. The uses of fibrous carbon are largely determined by its outstanding thermal and electrical properties and its fibrous quality. Because of their high heat-insulation properties carbon felts and wools are used first of all as a high-temperature insulating material. Its electrical properties are utilized for flexible heating elements (e.g. graphite cloth). In the same manner as glass fibre is used to reinforce plastics, fibrous carbon and fibrous graphite can be employed to strengthen plastics used, for instance, in ablative cooling. Likewise graphite bodies can be reinforced by fibrous carbon. Author

N69-25527/ Union Carbide Corp., Oak Ridge, Tenn. Y-12 Plant.
FABRICATION OF GRAPHITE FIBER REINFORCED GRAPHITE COMPOSITES

J. L. Cook and F. Lambdin 10 Jan. 1969 12 p refs Presented at WESTEC Conf. of the Am. Soc. for Metals, Los Angeles, 10-13 Mar 1969

(Contract W-7405-ENG-26)

(V-DA-2679; Conf-690306-1) Avail: CFSTI

Composites consisting of graphite fibers ($2 \mu\text{D} \times 0.010''\text{L}$) and either a thermoplastic or thermosetting resin were spray formed onto graphite mandrels; carbonized to $1,000^\circ\text{C}$, and densified as desired by repeated resin impregnation-carbonization cycles. Sections up to one inch in thickness and ranging in density from 0.2 to 1.7 g/cc have been fabricated using spraying as the basic fabrication method. Isostatic and match-die compaction were used to increase the fiber population. Preliminary physical and mechanical properties of these composite materials were evaluated.

Author (NSA)

N69-33802/ Sandia Corp., Albuquerque, N. Mex.
CHARACTERIZATION OF CARBON FABRICS AND FILAMENTS, CARBONIZING RESINS, CARBON-CARBON COMPOSITES, AND PROCESSING TECHNIQUES

H. A. MacKay Apr. 1969 30 p refs

(SC-RR-68-651) Avail: CFSTI

The properties of the carbon-carbon composite laminate are dependent on the type, composition, and orientation of the carbon or graphite reinforcement; the initial carbonizing resin binder; and certain processing parameters. The resin char yield after carbonization ranges from 15 to 85 percent; the phenolics and epoxyated novolacs provide 60-percent residual carbon. Carbon and graphite fabrics or yarns with no previous history of phosphorous flame retardant additives are recommended as reinforcements because they maintain fiber identity in the composite after carbonization. When carbonized at 1550°F , carbon-carbon laminates composed of a 60-percent carbon char forming resin and a square weave 99 percent carbon fabric show weight losses of 16 to 20 percent. After three reimpregnations with oxalic acid catalyzed furfuryl alcohol and three recarbonization cycles, these laminates retain 60 to 100 percent of noncarbonized control mechanical property values from 75° to 900°F . Author (NSA)

N69-33877/ Rocket Propulsion Establishment, Westcott (England).

SOME APPLICATIONS OF CARBONS AND GRAPHITES IN SPACETECHNOLOGY

A. C. Parmee 1969 13 p refs Presented at the 3d Brit. Interplanet. Soc. Symp. on Mater. in Space Technol., Bristol, Engl., 9-11 Apr. 1969

Copyright. Avail: CFSTI; HMSO

A variety of new and improved forms of carbon and graphite are described in terms of their method of manufacture and properties.

Some of the applications of these materials in aerospace technology are indicated and particular reference is made to pyrolytic carbon and its application in uncooled rocket nozzles and re-entry shields.

Author (ESRO)

N70-13741/ Union Carbide Corp., Oak Ridge, Tenn. Y-12 Plant. FIBER-REINFORCED GRAPHITE COMPOSITE FABRICATION AND EVALUATION

F. Lambdin, J. L. Cook, and G. B. Marrow 4 Sep. 1969 57 p refs

(Contract W-7405-eng-26)

(Y-1684) Avail: CFSTI

Composites consisting of carbon fibers (2 microns in diameter by 10 mils long), and either of a thermoplastic or thermosetting resin, were spray formed onto graphite mandrels, carbonized to 1,000 C, and densified by repeated impregnation-carbonization cycles. Sections up to one inch in thickness and ranging in density from 0.2 to 1.7 g/cc have been fabricated using spraying as the basic fabrication method. Isostatic and match-die compaction were used to increase the fiber population. Preliminary physical and mechanical properties of these composite materials were evaluated, and several were investigated to determine their performance under ablation conditions.

Author (NSA)

N70-13991/ Union Carbide Corp., Oak Ridge, Tenn. Y-12 Plant. CARBON COMPOSITE MATERIALS (SECOND ISSUE)

L. M. Mc Laughlin 18 Sep. 1969 314 p

(Contract W-7405-eng-26)

(Y-DA-2654) Avail: CFSTI

Reviews are presented on fabrication methods and properties of carbon-base thermal insulation, properties of pyrolytic graphite, fibrous graphite and carbon foam, preparation and properties of high-carbon compounds, properties of porous graphite, and morphology of rigid-foam carbon.

NSA

diameter, more isotropic reinforcements and stronger, more isotropic binder matrices.

A separate task within this program sought to develop an improved binder matrix from pitch by use of additives. Both No. 1512 pitch (softening point, 87 C) and a 150 C (softening point) pitch were used. Additives included sulfur, FeCl₃, phenolic resin, furane resin, epoxies, polyacrylonitrile, acrylic resins, and polyamide. Coking-value studies showed that the already high coking value of the 150 C pitch was not affected significantly by any of the additives. Further, it was concluded that the impregnating qualities of the 150 C pitch were not improved upon by any of the additives investigated.

Ablation studies on four-directional, 3-D composite of rayon and PAN precursor yarns indicate that the rayon precursor carbons were preferentially etched from the pyrolytic carbon matrix material whereas the PAN carbons were left in relief. This is taken to mean that the PAN carbons are more resistant to oxidation than rayon carbons.

Improved Graphite Materials for Re-Entry Vehicles, E. R. Stover, General Electric, Contract No. F33615-68-C-1283, Report No. AFML-TR-69-67, Vol III (April, 1970) (142 pages, 16 tables, 122 figures).

Others

From CAB

6179-2 Graphite for Reentry Applications

Processing studies and preliminary material-characterization data are described for three-dimensionally reinforced carbon/carbon composites. Experiments in which yarns were woven in 4, 5, and 7 directions were performed. Three-dimensional composites in which both PAN and rayon precursor yarn were woven in 4 directions were fabricated using 150 C (softening point) pitch or a mixture of 150 C pitch with another material. Mechanical and thermophysical properties were determined. The conclusion is that anisotropy limits the applications of this material. For example, the tensile strength was shown to decrease from about 9000 psi along a fiber direction to about 2000 psi at 50 degrees to the fiber. The large thermal-expansion anisotropy and distortions experienced during thermal processing were also serious disadvantages. It is recommended that the unidirectional 3-D composites would be improved by using smaller

CARBON-CARBON MATERIALS FOR AEROSPACE APPLICATIONS. H. M. Stoiler and E. R. Fry (Sandia Corp., Albuquerque, N. Mex.), p. 193-212.

IN: AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS AND AMERICAN SOCIETY OF MECHANICAL ENGINEERS, STRUCTURES, STRUCTURAL DYNAMICS AND MATERIALS CONFERENCE, 10TH, NEW ORLEANS, LA., APRIL 14-16, 1969, PROCEEDINGS. [A69-25407 12-32]

New York, American Society of Mechanical Engineers, 1969.

Carbon-carbon materials have attractive possibilities for increasing the capabilities of aerospace vehicle systems. Characteristics such as high heats of ablation, high strength-to-density ratios, and mechanical strength improvement at elevated temperatures result in a structural material that is highly resistant to reentry thermal environments. This paper presents a current summary on the status of carbon-carbon composite development and evaluation. Composite reinforcement/matrix combinations are described along with associated fabrication techniques. Mechanical, thermal, and ablation property data are presented for typical composites. The unique design parameters and their dependence on fabrication technique are also discussed.

AMERICAN CARBON COMMITTEE AND BOSTON COLLEGE,
NINTH BIENNIAL CONFERENCE ON CARBON, CHESTNUT
HILL, MASS., JUNE 16-20, 1969, SUMMARY OF PAPERS.
University Park, Pa., American Carbon Committee, 1969. 218 p.
\$10.00

NEW MEXICO SECTION OF AMERICAN SOCIETY OF
MECHANICAL ENGINEERS AND UNIVERSITY OF NEW
MEXICO COLLEGE OF ENGINEERING, CARBON COM-
POSITE TECHNOLOGY SYMPOSIUM, 10TH, ALBUQUERQUE,
N.M., JANUARY 29-30, 1970, PROCEEDINGS.
Albuquerque, N.M., American Society of Mechanical Engineers,
New Mexico Section, 1970. 356 p. \$7.50

Metallic-Carbide Composites

From IAA

A65-23321 *

A NEW CLASS OF HYPEREUTECTIC CARBIDE COMPOSITES.

E. G. Kendall, J. I. Slaughter, and W. C. Riley (Aerospace Corp., Materials Sciences Laboratory, El Segundo, Calif.).

IN: AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS, STRUCTURES AND MATERIALS CONFERENCE, 6TH, PALM SPRINGS, CALIF., APRIL 5-7, 1965. [A65-23300 13-32] New York, American Institute of Aeronautics and Astronautics, 1965, p. 212-218. 10 refs.

Contract No. AF 04(695)-469.

Discussion of extremely high thermal shock resistance in the Group IV-A carbides (TiC, ZrC, HfC) achieved by the fabrication of carbide-graphite composites using vacuum arc melting and casting techniques. High purity materials were employed to ensure a low interstitial content. Gravity and skull casting have been employed to produce test shapes. The eutectic composition between the monocarbide and terminal graphite phase has been defined in each system. When carbon content exceeds the eutectic composition, the excess precipitates from the liquid as platelets within the eutectic matrix. Mechanical properties have been determined at room temperature on Ti-C and Zr-C materials. A sharp demarcation has been noted at the eutectic point, where, in the Ti-C system compressive strengths of 240,000 psi for hypoeutectic material decrease to 30,000 psi for hypereutectic material. Similarly, flexure strength drops from 30,000 to 10,000 psi. Thermal shock resistance was evaluated in both 200 kw and 5 Mw air arc tunnels at heating rates of 700, 1800, and 2400 Btu/ft²/sec. No evidence of failure was noted in hypereutectic materials within any of the three systems. In comparative testing with tungsten and graphite, HfC-C showed marked superiority by exhibiting no measurable recession whatsoever when exposed to a heat flux of 700 Btu/ft²/sec.

(Author) M.M.

A68-19909

NEW FIBERS FOR STRUCTURAL REINFORCEMENTS.

R. C. White (Texaco Experiment, Inc., Richmond, Va.).

American Society for Metals, National Metal Congress and Exposition, Cleveland, Ohio, Oct. 16-19, 1967, Paper C 7-16.2. 13 p.

Members, \$1.50; nonmembers, \$3.00.

Evaluation of the state of development of the more advanced fiber materials for structural reinforcement, emphasizing the newer, very high-modulus, lightweight fibers available. Two processes for producing boron fibers are outlined, and carbon, silicon carbide, and other compound filaments are discussed. The coating of fibers in order to increase their resistance to oxidation and chemicals is detailed.

B.B.

A68-24289 *

BIAXIAL FRACTURE STRENGTH AND MECHANICAL PROPERTIES OF GRAPHITE-BASE REFRACTORY COMPOSITES.

Tu-Lung Weng (Union Carbide Corp., Carbon Products Div., Parma, Ohio).

American Institute of Aeronautics and Astronautics, and American Society of Mechanical Engineers, Structures, Structural Dynamics and Materials Conference, 9th, Palm Springs, Calif., Apr. 1-3, 1968, AIAA Paper 68-337. 15 p. 25 refs.

Members, \$1.00; nonmembers, \$1.50.

Contract No. AF 33(615)-3110.

Biaxial stress-strain properties of a graphite-base refractory composite have been determined at room temperature with thin-walled cylindrical specimens subjected to combinations of internal pressure, external pressure, and axial load. Stress and strain under combined stresses have been correlated with a generalized stress-strain relation. Biaxial fracture strength can be predicted satisfactorily by the modified maximum stress theory in the biaxial tensile stress state and by the fracture criterion proposed by Norris et al. in the other stress states. Biaxial fracture envelopes as functions of porosity and composition have also been obtained with these theories of fracture for the composites. Microscopic examination has indicated that intergranular, cleavage fractures were initiated from pores.

(Author)

A68-30320 *

SILICON CARBIDE WHISKERIZED CARBON FIBER.

R. G. Shaver (General Technologies Corp., Reston, Va.).

American Institute of Chemical Engineers, Materials Conference, Symposium on Plastics - High Temperature Reinforcements, Part I, Philadelphia, Pa., Mar. 31-Apr. 4, 1968, Paper 24 E. 8 p. 7 refs.

\$0.50.

Description of the whiskerizing process for growing whiskers onto virtually any surface able to withstand elevated temperatures for short times. The growth of whiskers is accomplished by a high-temperature process in which all the components necessary to form the whisker crystals are transported through the vapor phase. Thus the silicon carbide whiskers are grown from a vapor phase containing silicon and carbon in the form of gaseous compounds. The carbon fiber serves merely as a substrate on which nucleation of the whiskers occurs as these vapor-phase constituents react in the surrounding atmosphere. Many substrates may serve the same purpose, as, for example, silicon carbide polycrystalline monofilament and quartz filament, both of which have been whiskerized by this process. By the same token, whiskers of other ceramic materials such as aluminum oxide may also be formed by variations of the process.

M.M.

A68-44801

FABRICATION AND CHARACTERIZATION OF METAL CARBIDE-GRAPHITE COMPOSITES.

Y. Harada, S. A. Borts, and S. L. Blum (IIT Research Institute, Chicago, Ill.).

IN: METALLWERK PLANSEE, PLANSEE SEMINAR, 6TH, REUTTE, AUSTRIA, JUNE 24-28, 1968, PREPRINTS, VOLUME 2 [METALLWERK PLANSEE, PLANSEE SEMINAR, 6TH, REUTTE, AUSTRIA, JUNE 24-28, 1968, VORABDRUCKE, VOLUME 2]. [A68-44797 24-17]

Reutte, Austria, Metallwerk Plansee AG, 1968. 44 p. 14 refs.

Refractory metal carbide-graphite composites were prepared by hot pressing at 2600 to 3200°C. The effect of variations in composition and processing on flexural, tensile and compressive strengths; thermal expansion and conductivity; high temperature deformation, and electrical resistivity were determined, both parallel and perpendicular to the hot pressing direction. The NbC-C and TaC-C systems were principally studied while other systems such as TiC-C, ZrC-C, HfC-C, VC-C, MoC(1-x)-C and WC-C were also investigated. Excellent high temperature behavior was generally exhibited. At a carbide content of 20 vol %, flexural strengths at 2000°C of over 12,000 psi were measured in the with-grain direction. TaC-C composites displayed the highest elevated temperature strength and resistance to plastic deformation. Composites containing 80 vol % TaC displayed flexural strengths of over 20,000 psi in both grain directions up to 2500°C, superior to that for any commercial graphite or pure TaC. It was also determined that with increasing carbide content, higher strength, decreasing anisotropy, decreasing resistance to high temperature deformation and decreasing electrical resistivity occur. (Author)

A69-20501

LAMINATES AND FILAMENT-WOUND STRUCTURES OF WHISKERIZED HIGH-MODULUS CARBON FIBER.

Robert G. Shaver (General Technologies Corp., Reston, Va.).

IN: SOCIETY OF THE PLASTICS INDUSTRY, ANNUAL TECHNICAL CONFERENCE, 24TH, WASHINGTON, D.C., FEBRUARY 4-7, 1969, PROCEEDINGS. [A69-20478 08-18]

New York, Society of the Plastics Industry, Inc., 1969, p. 15-B, 1 to 15-B, 12. 7 refs.

The purpose of the work was to develop the processing techniques necessary to fabricate high fiber content laminates and filament-wound structures of high modulus carbon fibers that had been treated by growing silicon carbide whiskers (whiskerizing) upon their surfaces. Compositing techniques in epoxy resin matrix were developed using both laminating and filament winding. A polyimide laminating technique was also developed. The techniques for lamination involve the preparation of laminar tapes from whiskerized fiber, prepregging the tapes with the desired resin, and molding of test pieces for evaluation. Filament winding has proceeded along a parallel path in which long-length carbon fiber yarn or tow which has been whiskerized is then prepregged with resin and hardener, filament-wound, and cured. The current test pieces are in the form of NOL rings. The results demonstrate the feasibility of whiskerized graphite composites for structural application. (Author)

A69-32150 *

BIAXIAL FRACTURE STRENGTH AND MECHANICAL PROPERTIES OF GRAPHITE-BASE REFRACTORY COMPOSITES.

Tu-Lung Weng (Union Carbide Corp., Carbon Products Div., Parma, Ohio).

[American Institute of Aeronautics and Astronautics and American Society of Mechanical Engineers, Structures, Structural Dynamics and Materials Conference, 9th, Palm Springs, Calif., Apr. 1-3, 1968, AIAA Paper 68-337.]

AIAA Journal, vol. 7, May 1969, p. 85-858. 26 refs.

Contract No. AF 33(615)-3110.

Biaxial stress-strain properties of a graphite-base refractory composite have been determined at room temperature with thin-walled cylindrical specimens subjected to combinations of internal pressure, external pressure, and axial load. Stress and strain under combined stresses have been correlated with a generalized stress-strain relation. Biaxial fracture strength can be predicted satisfactorily by the modified maximum stress theory in the biaxial tensile stress state and by the fracture criterion proposed by Norris et al. in the other stress states. Biaxial fracture envelopes as functions of porosity and composition have also been obtained with these theories of fracture for the composites. Microscopic examination has indicated that intergranular, cleavage fractures were initiated from pores. (Author)

A69-35526

DIBORIDE MATERIALS, CANDIDATES FOR AEROSPACE APPLICATIONS.

Edward V. Clougherty, Edward T. Peters, and David Kalish (ManLabs, Inc., Cambridge, Mass.).

IN: MATERIALS AND PROCESSES FOR THE 70'S; SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS, NATIONAL SYMPOSIUM AND EXHIBITION, 15TH, LOS ANGELES, CALIF., APRIL 29-MAY 1, 1969, PROCEEDINGS. (A69-35501 19-15)

North Hollywood, Western Periodicals Co.; Azusa, Calif., Society of Aerospace Material and Process Engineers (Science of Advanced Materials and Process Engineering Proceedings, Volume 15), 1969, p. 207-308. 9 refs.

Contract No. AF 33(615)-3671.

Polycrystalline diboride materials fabricated by hot pressing zirconium boride or hafnium boride with refractory additives such as silicon carbide and carbon are characterized by improved fabricability and enhanced material properties relative to the base diboride. Materials-centered evaluations of oxidation, thermal, physical, and mechanical properties yield excellent relative ratings for the diboride materials compared to other candidate high-temperature materials. Environment-centered and specific application-oriented evaluations demonstrate that diboride materials should be considered for nosecones, lifting reentry leading edges, air breathing engine components, rocket nozzle throats, and other aerospace applications. (Author)

A69-36320

HIGH-TEMPERATURE MATERIALS.

Murray A. Schwartz (IIT Research Institute, Ceramics Div., Chicago, Ill.).

Space/Aeronautics, vol. 52, July 1969, p. 95-98, 102, 108, 116, 117. 15 refs.

Discussion of various types of high-temperature materials for aerospace and spacecraft applications. The carbon/carbon composites appear attractive for reentry nose cones because of their high thermal shock resistance, for turbine vanes and buckets because of their high strength-to-density ratio, for rocket nozzles because of their ease of fabrication, and for a wide variety of other applications because they can be tailored. Radomes, optical windows, and nonballistic reentry leading edges have been the principal applications for oxides and their composites. Carbide composites and graphite developments are considered. Ablative systems are based on polymers that decompose, melt, and vaporize, thus absorbing heat and keeping the subsurface cool. Applications of fibers are considered, and high-temperature metals and coatings are discussed. G.R.

A70-20387 *

BORIDE COMPOSITES—A NEW GENERATION OF NOSE CAP AND LEADING EDGE MATERIALS FOR REUSABLE LIFTING REENTRY SYSTEMS.

Larry Kaufman (ManLabs, Inc., Cambridge, Mass.).

American Institute of Aeronautics and Astronautics, Advanced Space Transportation Meeting, Cocoa Beach, Fla., Feb. 4-6, 1970, Paper 70-278. 10 p.

Members, \$1.00; nonmembers, \$1.50.

Contracts No. AF 33(615)-3859; No. AF 33(615)-3671.

New boride composites for long time applications in oxidizing environments between 2500 deg F and 5000 deg F have been developed which exhibit high strength, thermal conductivity and resistance to thermal stress under lifting reentry conditions. State-of-the-art size limitations are in the one half to one foot range. Multicycle exposures to ten or more arc plasma tests (each of 1800 seconds) at a stagnation pressure near 5 psi, stagnation enthalpy of 10,000 BTU/lb and heat flux of 500 Btu/sq ft sec at surface temperatures near 4500 deg F yield recessions of 20 mils after 23,000 seconds of exposure. These conditions simulate a three inch nose radius at an altitude of 180,000 ft and a velocity of 22,000 ft/sec. This behavior is unrivaled by any known material. Temperature gradients of 1500 deg F have been measured through 400 mils of these composites under these conditions implying attractive insulation characteristics. (Author)

A70-31315 High modulus fibers and composites. F. S. Galasso (United Aircraft Research Laboratories, East Hartford, Conn.). New York, Gordon and Breach, Science Publishers, Inc., 1969. 117 p. 105 refs. \$9.50.

Description of the current state of development of high modulus continuous fibers and the epoxy-resin and metal-matrix composites which contain these fibers. The information is intended for fiber researchers, composite workers, and those interested in the most advanced structural materials. The general features of fibers and composites are examined, including glass fibers, metal fibers, whiskers, and high modulus filaments. Extensive data are provided for the preparation, microstructure, structure, and properties of carbon fibers and boron fibers. Also treated are silicon carbide, boron nitride, boron carbide, titanium diboride, and oxide fibers. Organic and metal matrix composites are described, and natural or eutectic composites are also covered. T.M.

From STAR

N65-14834# Union Carbide Corp., Lawrenceburg, Tenn. Carbon Products Div. **IMPROVED GRAPHITE MATERIALS FOR HIGH-TEMPERATURE AEROSPACE USE. VOLUME II: DEVELOPMENT OF GRAPHITE-REFRACTORY COMPOSITES** Technical Documentary Report, 1 May 1963-30 Apr. 1964. R. M. Bushong et al. Wright-Patterson AFB, Ohio, AF Mater. Lab., Oct. 1964. 143 p refs. (Contract AF 33(657)-11171) (ML-TDR-64-125, Vol. II; AD-609247)

Studies were conducted on the following composite changes: zirconium, silicon, and niobium replacement of boron; and niobium, cerium, and lanthanum replacement of silicon. Studies of graphite-oxide reactions provided information concerning the stability of oxide coatings in contact with carbon bodies. Insight was gained into the mechanisms of such reactions when their limits of stability are exceeded. A high-temperature apparatus was developed to supplement existing oxidation tests at this laboratory. Cyclic tests of short duration were completed on grade ATJ, SiC-coated RVC, and grade JTA. Additional tests using exposures of 5, 15, 30, and 60 minutes over the temperature range of 1400° to 1800° C were performed on grade JTA. These data were used as a basis for screening new composites. The most oxidation-resistant composite was JT-0981 in which the boron was completely replaced with silicon. Author

N66-13096# IIT Research Inst., Chicago, Ill. **GRAPHITE-METAL COMPOSITES** Quarterly Report No. 1, 1 Aug.-1 Nov. 1965. Y. Harada 18 Oct. 1965. 22 p refs. (Contract NASr-65(09)) (NASA-CR-68387; IITRI-G6003-1) CFSTI: HC \$1.00/MF \$0.50 CSCL 13H

Equipment modifications for improved hot press processing were incorporated including the introduction of a constant pressure device. An improved venting system has virtually eliminated error inducing fumes in the optical pyrometry. Calibration of the hot pressing operation has shown that the sample temperature is closely indicated by the present arrangement of a sight tube inserted into the mold. Attempts to hot press calcined petroleum coke at 3000° C with no metal additives produced highly graphitic structures which exhibit poor bonding. Studies of heterogeneity in densities of niobium and hafnium graphite composites showed that it is a result of

carbide particle segregation. Examination of microstructures shows that denser sections contain larger and more numerous carbide grains. These sections probably contain amounts of metal in excess of the designed composition. Flexural strength either shows an inverse relation with density or is the same for different densities due to particle segregation. The usual direct relationship was not observed. Thus, higher density values alone are not always real indication of higher densification. R.N.A.

N66-17087# IIT Research Inst., Chicago, Ill. **GRAPHITE-METAL COMPOSITES** Quarterly Report No. 2. Y. Harada and G. A. Rubin 21 Jan. 1966. 32 p refs. (Contract NASr-65(09)) (NASA-CR-70320; IITRI-G6003-2) CFSTI: HC \$2.00/MF \$0.50 CSCL 11D

Compositional studies were made to determine the effect of graphite source material on the properties of Mo-C composites. Investigations of other systems incorporating tungsten, vanadium, hafnium, tantalum, niobium, and zirconium as the metal constituent were also conducted. Studies of time-temperature relationships in processing were initiated, and measurements of electrical resistivity were made. Among the conclusions are that the use of flat, platy particles as opposed to spherical cokes yield better bonding in graphite-metal composites. In the Nb-C system, room temperature flexural strengths of greater than 20000 psi and an increase in strength at 2000° C can be expected for compositions in the eutectic range. Work with the zirconium system shows that room temperature strengths in excess of 13000 psi can be realized at 50 wt% Zr. The processing temperature should not exceed the carbide-carbon eutectic temperature by more than about 50° C if significant loss of metal is to be avoided. C.T.C.

N66-23651# IIT Research Inst., Chicago, Ill. **GRAPHITE-METAL COMPOSITES** Quarterly Report No. 2. C. W. Boquist 25 Jan. 1965. 28 p. (Contract NASr-65(09)) (NASA-CR-74308; IITRI-B6030-2) CFSTI: HC \$2.00/MF \$0.50 CSCL 11F

The role of metals in graphite strengthening was investigated with the following alloying agents: Hafnium, tantalum, molybdenum, columbium, zirconium, boron, titanium, beryllium, uranium, and thorium. Carbon and metal powders were dry-mixed, poured into a graphite mold, and hot-pressed. Results showed that individual metals have an intrinsic ability to strengthen the graphite lattice, and that this ability varies from metal to metal even at similar weight or atomic percentages. Thorium-carbon compacts were the only systems that showed internal cracking; all other systems possessed good microstructures. G.G.

N66-26236# IIT Research Inst., Chicago, Ill. **GRAPHITE-METAL COMPOSITES** Quarterly Report No. 3, Feb. 1-May 1, 1966. Y. Harada 21 Apr. 1966. 42 p refs. (Contract NASr-65(09)) (NASA-CR-74904; IITRI-G6003-3) CFSTI: HC \$2.00/MF \$0.50 CSCL 11F

Progress is reported in a program to investigate liquid phase sintering in graphite-metal composites during hot pressing at elevated (2800° C to 3100° C) temperatures. Compositional studies included a broad study of tantalum and niobium composites having metal contents of 50 to 90 wt%. In addition, systems containing molybdenum, vanadium, and titanium, were examined in a continuing general study of metal carbide-graphite composites and their properties. The use of metal oxides as the metal source was examined, and

experiments were conducted to determine actual metal content in fabricated billets. Physical property measurements were made at elevated temperatures, and thermal shock tests were initiated. C.T.C.

N66-28334* General Electric Co., Philadelphia, Pa. Missile and Space Div.

STUDY OF THE GROWTH PARAMETERS INVOLVED IN SYNTHESIZING BORON CARBIDE FILAMENTS Final Report

A. Gatti, C. Mancuso, E. Feingold, and R. Jakas 1 Mar. 1966 53 p refs

(Contract NASw-1205)

(NASA-CR-75673; GE-214-269) CFSTI: HC \$3.00/MF \$0.50 CSCL 07B

Boron carbide (B_4C) whiskers exhibit attractive properties for utilization in composite materials. In terms of their high strength, low density, and high elastic modulus. These whiskers when utilized as reinforcements, offer great potential for high strength-to-weight or high stiffness-to-weight materials for future applications. B_4C whiskers were grown by the vaporization at high temperature of B_4C powder and the subsequent condensation of this vapor in the form of whiskers at a lower temperature. Strength measurements were made on typical whisker specimens at both room and elevated temperatures. A room temperature tensile strength of 2×10^8 psi was measured for one such whisker. Characterization studies of B_4C whiskers by X-ray techniques, light microscopy techniques, and electron microscopy techniques were made. Composites utilizing B_4C whiskers embedded in an aluminum matrix were fabricated by hot pressing and liquid infiltration methods and tested in tension at room and elevated temperatures. Author

N66-29220* IIT Research Inst., Chicago, Ill.

GRAPHITE-METAL CARBIDE COMPOSITES

Y. Harada Washington, NASA, Jun. 1966 70 p refs

(Contract NASr-65(09))

(NASA-CR-507) CFSTI: HC \$3.00/MF \$0.75 CSCL 11D

Investigations have been conducted to determine the feasibility of fabricating metal-graphite composites by hot pressing at 2800°-3000°C. Mixtures of calcined petroleum coke with varying amounts of different metals (or their carbides) were used as the raw materials, and no binders were involved in this simple, one-step process. Ten metal additions were studied in this program: niobium, hafnium, molybdenum, tantalum, zirconium, titanium, boron, beryllium, uranium, and thorium. Evaluation of the resulting bodies included measurements of physical properties and examination of microstructure. The results show that strong, dense bodies can be realized by this method. Liquid phase sintering occurs through formation and diffusion of a carbide-carbon eutectic under the hot pressing conditions, and subsequent recrystallization of this phase yields strong bonding. The strongest bodies to emerge from these studies are in the Nb-C, Hf-C, and Mo-C systems. Author

N66-34066* IIT Research Inst., Chicago, Ill.

GRAPHITE-METAL COMPOSITES Final Report, 1 Aug. 1965-31 Jul. 1965

Y. Harada 1 Aug 1966 110 p refs

(Contract NASr-65(09))

(NASA-CR-771:4) CFSTI: HC \$4.00/MF \$0.75 CSCL 13H

Hot pressed metal carbide-graphite composites, incorporating carbides of titanium, zirconium, hafnium, vanadium, niobium, tantalum, molybdenum, or tungsten with compositional ranges of up to 90 wt%, were studied. Processing temperatures varied from 2600° to 3200°C, and the effects on

physical and mechanical properties up to 2800°C were determined. Needle cokes were found to be preferable to spherical particle graphite sources in achieving rapid densification. At 50 wt% metal level in any system, hot pressing just below the eutectic temperature produces composites having room temperature strengths of over 10,000 psi. The metal phase enhances ordering of the graphite phase, and improved bonding occurs through liquid phase sintering and/or diffusion bonding. High temperature behavior is related to the liquification temperature. An essentially linear relationship between electrical resistivity and flexural strengths is reported. Author

N67-12072* IIT Research Inst. Chicago, Ill.

METAL CARBIDE-GRAPHITE COMPOSITES Quarterly Report, Aug. 1-Oct. 31, 1966

Y. Harada 27 Oct. 1966 24 p refs

(Contract NASr-65(09))

(NASA-CR-79757; QR-1) CFSTI: HC \$1.00/MF \$0.50 CSCL 11F

Property investigations were conducted on TaC-C and NbC-C compositions of 50 to 90 wt% metal. Flexural tests at temperatures up to 2800°C, and compressive deformation studies at 2700°C were performed. Thermal expansion was measured in the range of room temperature to 2300°C, and electrical properties were evaluated. Measurements were also made to determine if the previously observed linear relationship between electrical conductivity and flexural strength for graphite matrix composites applied to materials of high metal carbide content. Among the most significant findings are: (1) In high carbide content composites the anisotropy ratio in flexural strength diminishes to 1.5. (2) Anisotropy in thermal expansion behavior diminishes with increasing carbide content. (3) Resistance to compressive deformation at high temperatures is greater for the TaC-C than for the NbC-C system. (4) A definite direct correlation exists between electrical and mechanical properties, and this relationship may be exploited as a method for determining degree and homogeneity of bonding. M.G.J.

N67-12273* Texaco Experiment, Inc., Richmond, Va.

INVESTIGATION OF FIBER SYSTEMS OF ABLATIVE MATERIALS Final Report

Gordon H. Miller and George C. Robinson, Jr. 30 Sep. 1965 173 p refs

(Contract NAS3-4196)

(NASA-CR-54722; TEL-TP-259) CFSTI: HC \$5.00/MF \$1.00 CSCL 11F

The desired properties for advanced fibers to be used as reinforcing agents for ablative composites were defined after consideration of the ablation process and the anticipated environmental conditions in advanced thrust chambers of liquid-fuel rocket engines. Based on their physical properties and their calculated and experimentally determined resistance to the combustion products from H_2/F_2 or B_2H_6/O_2 fuel-oxidizer combustions, graphite, tungsten-coated boron, TiC, TiB_2 , ZrB_2 , B_4C , ZrO_2 , and carbon-coated boron were recommended. The feasibility of preparing fibers of graphite, tungsten-coated boron, TiB_2 , TiC, and ZrB_2 by chemical vapor plating was investigated. The TiB_2 fibers had the highest strengths (up to 378 kpsi) and highest moduli (up to 84 million psi) of all the fiber materials investigated. Fibers of these materials were tested in an argon arc plasma to determine their chemical resistance to oxidizing media consisting of separately injected H_2O and BF_3 . Author

N67-19010* Los Alamos Scientific Lab., N. Mex.

CARBIDE-GRAPHITE COMPOSITES

K. V. Davidson, H. E. Riley, and J. M. Taub 19 Oct. 1966 61 p refs

(Contract W-7405-ENG-3)

(LA-3569-MS) CFSTI: HC \$3.00/MF \$0.65

The effects of process variables on the high temperature properties of hot pressed carbide-graphite composites is not well understood. A program to evaluate these effects by holding certain variables constant is described. The results of the effects of these variables are reported and include powder characterization, hot pressing conditions, composition, carbide versus metal powder additions, binder content, graphite particle size and type, and correlation of microstructures with resistance to deformation at elevated temperatures.

Author (NSA)

N67-19056*# IIT Research Inst., Chicago, Ill.
METAL CARBIDE-GRAPHITE COMPOSITES Quarterly Report, 1 Nov. 1966-31 Jan. 1967
 Y. Harada 31 Jan. 1967 35 p refs

(Contract NASr-65(09))

(NASA-CR-82527; IITRI-G6003-2; QR-2) CFSTI: HC \$3.00/MF \$0.65 CSCL 11D

Fabrication of metal carbide-graphite composites by hot pressing at temperatures up to 3200°C, and the determination of physical and mechanical properties of these materials are examined. The relationship between electrical conductivity and flexural strength is evaluated. Mixing laws for multiphase systems were employed to analyze electrical and mechanical properties. Heat treatment studies were conducted to examine annealing effects on physical and mechanical properties. Among the major conclusions were that high strengths are directly related to soaking of composites at processing temperature and also to the use of higher temperatures. A linear relationship appears between electrical conductivity and flexural strength for the NbC-C system in the compositional range, 20-58 volume per cent NbC. Heat treatment of high NbC content composites subsequent to hot pressing can result in significant improvement in strength due to sintering and diffusion bonding. The annealing process also produces dimensional changes due to relief of stresses which are imparted to billets on cooling after processing.

S.P.

N67-27434*# IIT Research Inst., Chicago, Ill.
METAL CARBIDE-GRAPHITE COMPOSITES Quarterly Report

25 Apr. 1967 36 p refs

(Contract NASr-65(09))

(NASA-CR-84437; IITRI-66003-3; QR-3) CFSTI: HC \$3.00/MF \$0.65 CSCL 11F

Research in fabricating metal carbide-graphite composites by hot pressing at temperatures up to 3200°C, and in determining the physical and mechanical properties of these materials is reported. Experiments were conducted to more accurately establish hot pressing temperatures employing NbC-C eutectic formation as the indicator. Compositional studies were conducted, and include systems incorporating zirconium carbide and hafnium carbide in addition to the TaC-C and NbC-C systems. Property determinations were concerned with flexural and tensile strength, flexural creep at 2400°C, and thermal expansion up to 2300°C.

C.T.C.

N67-29555# Carborundum Co., Niagara Falls, N. Y.
ADVANCED CERAMIC SYSTEMS FOR ROCKET NOZZLE APPLICATIONS Quarterly Progress Report, 1 Nov. 1966-28 Feb. 1967

Bruno R. Miccioli 15 Mar. 1967 11 p refs

(Contract N00017-67-c-2406)

(QR-1; AD-650508) CFSTI: HC \$3.00/MF \$0.65

The possibilities for mating refractory carbides with Carb-I-Tex are being investigated. Composite structures, suitable for evaluation by sub-scale motor firings, are being fabricated. The carbide-graphite composite system has been applied to a pilot ejection catapult nozzle requiring both high mechanical shock and thermal shock resistance. Three nozzles have been submitted for testing. The thermal shock tests conducted by TRW, Inc. are reported. Although limited, these indicate resistance tendencies as a function of composition.

Author (TAS)

N67-37296# Los Alamos Scientific Lab., N. Mex.
CARBIDE-GRAPHITE COMPOSITES Progress Report
 K. V. Davidson, R. E. Riley, and J. M. Taub 15 Jun. 1967
 15 p refs

(Contract W-7405-ENG-36)

(LA-3652-MS; PR-2) CFSTI: HC \$3.00/MF \$0.65

Data on the effect of composition, binder content, and contaminants in the as-received carbide and graphite powders are presented. The effect of pressure on deformation of extruded composites at high temperatures is discussed. Also presented are preliminary determinations of the effect of composition of TaC-C composites, TaC-NbC solid solution, and composites of TaC-NbC mixtures. Preliminary data on the dynamic elastic properties and electrical resistivity of NbC-C composites are given.

Author (NSA)

N67-38851*# IIT Research Inst., Chicago, Ill.
METAL CARBIDE-GRAPHITE COMPOSITES Summary Report, 1 Aug. 1966-31 Jul. 1967

29 Sep. 1967 131 p refs

(Contract NASr-65(09))

(NASA-CR-89073) CFSTI: HC \$3.00/MF \$0.65 CSCL 11D

Niobium carbide-graphite and tantalum carbide-graphite composites were fabricated by hot pressing at 3000° to 3250°C. The effect of carbide content on physical and mechanical properties was evaluated at room temperature and up to 2800°C. Room temperature studies show that with increasing carbide content in either composite, strength properties and electric conductivity increase, and anisotropy in properties decreases. Tests at 2000°C for any composite reveal an increase in flexural strength, a decrease in flexural modulus, little change in tensile strength, and a decrease in compressive strength. These changes indicate that the material should have an improved thermal shock resistance when rapidly cycled between ambient and 2000°C. Resistance to high temperature deformation follows no trend as a function of carbide content. The tantalum composite shows superior structural integrity at high temperatures. Measurement of thermal expansion and conductivity shows a trend toward isotropic behavior with increasing carbide content. At 80 vol% carbide, the with-grain and across-grain values for thermal expansion are about the same.

Author

N68-19220*# IIT Research Inst., Chicago, Ill.
FABRICATION AND CHARACTERIZATION OF METAL CARBIDE-GRAPHITE COMPOSITES

Y. Harada and G. A. Rubin 9 May 1966 26 p Presented at the 68th Ann. Meeting of the Am. Ceram. Soc., Washington, 9 May 1966

(Contract NASr-65)

(NASA-CR-75184) CFSTI: HC \$3.00/MF \$0.65 CSCL 11F

Refractory metal carbide-graphite composites have been prepared by hot pressing and the effect of variation of composition and processing conditions on phase equilibration and physical properties such as flexural strength, hardness, thermal shock resistance, thermal expansion, and electrical resistivity has been studied. The systems investigated include TiC-C, ZrC-C, HfC-C, VC-C, NbC-C, TaC-C, MoC-C and WC-C. It has been found that the strength of all the composite materials investigated increased with increasing carbide content reaching a peak for the metal-carbide-graphite eutectic composition. An essentially linear relationship between electrical resistivity and flexural strength was found to be useful to calculate the strength level of the material and to understand the strengthening mechanism with increasing carbide content.

Author

N68-27399*# IIT Research Inst., Chicago, Ill.
PROPERTIES OF TANTALUM CARBIDE-GRAPHITE AND NIOBIUM CARBIDE-GRAPHITE COMPOSITES

Y. Harada and S. A. Bortz [1967] 27 p refs Presented at the 69th Ann. Meeting of the Am. Ceram. Soc., New York, 2 May 1967

(Contract NASr-65(09)14-003-909)

(NASA-CR-85164) CFSTI: HC\$3.00/MF\$0.65 CSCL 11D

Tantalum carbide-graphite and niobium carbide-graphite composites were prepared by hot-pressing at 3000° to 3200°C. The effect of metal carbide content upon properties such as flexural strength, thermal expansion, compressive deformation, and electrical resistivity were determined, both parallel and perpendicular to grain direction. The results show that with increasing carbide content the following general trends are observed: higher strength, decreasing anisotropy, decreasing resistance to high temperature plastic deformation, and decreasing electrical resistivity. Author

N68-27531* IIT Research Inst., Chicago, Ill.

METAL CARBIDE-GRAPHITE COMPOSITES

Y. Harada 28 Apr. 1968 41 p refs

(Contract NASr-65(09))

(NASA-CR-95222; IITRI-G6003-Q7) CFSTI: HC \$3.00/MF \$0.65 CSCL 11D

Carbon powders of various sizes, shapes, and processing histories were incorporated into composites of 47 vol% NbC, in order to determine their effects on such properties as strength, thermal expansion, high temperature deformation resistance, and degree of anisotropy. Creep tests conducted at high temperatures show: (1) The best creep resistance in both grain directions is exhibited by composites incorporating M2 graphite. (2) A heat treatment of one hour at 2500°C does not materially change creep behavior of NbC-C composites. (3) Examination of compressive creep behavior at 2700°C, 2000 psi for 30 minutes, reveal changes in length of less than 1% in either grain direction. An evaluation of densification aids for TaC-C composites shows that 5 vol% of Mo, W, or NbC in composites containing about 45 vol% TaC yields dense, well-bonded composites with excellent high temperature properties. The preliminary data indicate that additives of about 50 vol% carbide content exhibit better creep resistance than equivalent TaC-C composites without additives. M.G.J.

N69-33874/ Aerospace Corp., El Segundo, Calif. Lab. Operations. ELASTIC BEHAVIOR OF ARC-CAST ZIRCONIUM CARBIDE-GRAPHITE ALLOYS, SEPTEMBER 1966-SEPTEMBER 1967

Ronald C. Rossi, Robert D. Carnahan, and K. R. Janowski Jan. 1969 21 p refs

(Contract F04701-68-C-0200)

(AD-687437; TR-0200(4250-10)-4; SAMSO-TR-69-121) Avail: CFSTI CSCL 11/2

The Youngs modulus and shear modulus of arc-cast zirconium carbide-graphite alloys were measured as a function of graphite content and were found to be dependent upon the microstructure of these alloys. Attempts to fit several theoretical analyses to the data were not successful. The simplified physical models from which these analyses were derived limit their usefulness in predicting elastic behavior for materials having complex microstructures. Author (TAB)

N68-37595/ Westinghouse Electric Corp., Pittsburgh, Pa. Astronuclear Lab.

COMPRESSIVE CREEP BEHAVIOUR OF NIOBIUM CARBIDE-GRAPHITE COMPOSITES

William F. Brizes and L. L. French 1967 22 p 11 refs

(WANL-TME-1761) CFSTI: HC\$3.00/MF\$0.65

The compressive creep behavior of cold pressed and sintered niobium carbide-graphite composites has been studied as a function of temperature and composition. The equation $\epsilon = A\sigma^{1.4} \exp \{5.0 [(volume \% porosity/100)] + [(volume \% NbC/100)]\}$ is proposed to represent the creep behavior of graphite-rich composites as a function of composition and stress. The activation energy, activation volume and stress dependence of creep were determined and the possible mechanisms controlling deformation were examined. Author (NSA)

N69-10902*/ IIT Research Inst., Chicago, Ill.

METAL CARBIDE-GRAPHITE COMPOSITES Summary Report No. 2, 1 Aug. 1967-31 Aug. 1968

15 Oct. 1968 140 p refs

(Contract NASr-65(09); IITRI Proj. G60C3)

(NASA-CR-97616) Avail: CFSTI CSCL 11F

Studies were conducted on controlling the properties of hot-pressed metal carbide-graphite composites. The effects of starting material processing history, morphology, purity level, and shape relationships on properties were investigated. Other studies were conducted on the effect of processing temperatures on the bonding and strength of these composites. Mechanical property measurements were used as a measure of the changes which occurred. In addition, creep behavior was factored into their evaluation as high temperature thermal shock resistant materials. These experiments indicated that properties can be controlled and that additives can be employed to lower fabrication temperatures and produce sound composites. Author

N69-1912,*/ IIT Research Inst., Chicago, Ill.

METAL CARBIDE-GRAPHITE COMPOSITES

Yoshiro Harada 23 Dec. 1968 26 p refs

(Contract NASr-65(09))

(NASA-CR-100023; IITRI-G6003-Q9) Avail: CFSTI CSCL 11D

The use of low-melting additives as densification aids is studied to normalize the fabrication process by lowering temperatures to 3000° C or lower and to improve composite properties. This report describes initial studies on the use of tungsten in NbC-C composites. Composites containing 25, 50, and 75 vol%/NbC were fabricated as the standards against which additive-containing composites could be evaluated. Additive composites of the NbC-WC-C systems containing from 25 to 75 vol% total carbides were then hot pressed for examination both at room temperature and at high temperatures. Detailed results are presented which suggest a good potential for lowering the fabrication temperature and for improving the composite properties. K.W.

N69-24923*/ IIT Research Inst., Chicago, Ill.

METAL CARBIDE-GRAPHITE COMPOSITES Final Report, 1 Sep. 1968-28 Feb. 1969

14 Apr. 1969 63 p refs

(Contract NASr-65(09))

(NASA-CR-100842; IITRI-G6003) Avail: CFSTI CSCL 11D

Studies were conducted on the use of WC as a densification aid for NbC-C composites in order to lower the fabrication temperature from 3200° to 3000°C. The compositions which were studied are: (1) carbide contents from 25 to 75 vol%; and (2) NbC-WC solid solutions from 10 to 21 mol% WC. Evaluation of composites included characterization of NbC-WC solid solutions, and examination of mechanical properties at temperatures up to 2500°C. The results show that fabrication temperatures can be lowered to a more easily obtainable 3000°C. Furthermore, composites of improved high temperature properties are realized with the incorporation of WC. The X-ray analysis of the various composites showed the presence of NbC-WC solid solutions and graphite; there was no evidence of free WC which could effect high temperature properties adversely. Author

N69-28517/ Los Alamos Scientific Lab., N. Mex.

EXTRUDED CARBIDE-GRAPHITE COMPOSITES

R. E. Riley, N. K. Richerson, and D. H. Schell 15 Oct. 1968 14 p refs

(Contract W-7405-eng-38)

(LA-4077) Avail: CFSTI

Preliminary data on the mechanical and physical properties of extruded carbide-graphite composites are presented. The results

include the effect of carbide content on the room-temperature compression and flexure strength and on resistance to deformation at elevated temperatures. Also presented are data on room-temperature electrical resistivity, thermal expansion to 2000°C in the across-grain and with-grain directions, modulus of elasticity as a function of temperature, and metallography. Author (NSA)

N69-39567/ Aeronautical Research Labs. Melbourne (Australia).
THE STRUCTURE OF CARBON FIBRES AND GRAPHITE
R. A. Coyle and L. M. Gilin Feb. 1969 29 p refs
(ARL/ME-63) Avail: CFSTI

This review compares and contrasts the structure and mechanical properties of carbons and graphites in fibre and bulk forms. In particular, the relation of the structural parameters—crystal perfection, preferred orientation and crystallite growth—to modulus and strength is examined. The effect on strength of fibres of impurity atoms in the carbon structure and atomic defect arrangements in the intercrystallite regions is discussed, and suggestions for future research made. Author

N69-40680/ IIT Research Inst., Chicago, Ill.
FABRICATION AND CHARACTERIZATION OF METAL CARBIDE-GRAPHITE COMPOSITES
Y. Harada, S. A. Bortz, and S. L. Blum. In Plansee Soc. for Powder Met. 6th Plansee Seminar Preprints, Vol. 2 1968 44 p refs
(See N59-40674 24-17)
Avail: CFSTI

Refractory metal carbide-graphite composites were prepared by hot pressing at 2600° to 3200°C. The effect of variations in composition and processing on flexural, tensile and compressive strengths, thermal expansion and conductivity, high temperature deformation, and electrical resistivity were determined, both parallel and perpendicular to the hot pressing direction. The NbC-C and TaC-C systems were principally studied while other systems such as TiC-C, ZrC-C, HfC-C, VC-C, MoC_(1-x)-C and WC-C were also investigated. TaC-C composites displayed the highest elevated temperature strength and resistance to plastic deformation. Composites containing 80 vol% TaC displayed flexural strengths of over 20,000 psi in both grain directions up to 2500°C, superior to that for any commercial graphite or pure TaC. It was also determined that with increasing carbide content, higher strength, decreasing anisotropy, decreasing resistance to high temperature deformation and decreasing electrical resistivity occur. Author

N70-13761/ Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
HEAT-RESISTANT MATERIAL WITH SILICON CARBIDE ASA BASE
S. A. Tsukerman et al 13 May 1969 11 p Transl. into ENGLISH from Poroshkovaya Met. v Novoi Tekhnika (Moscow), 1968 p 63-67
(AD-693859; FTD-MT-24-64-69) Avail: CFSTI CSCL 11/4

A new high-temperature material, termed SG-60, is a silicon carbide-graphite composite in which the graphite is the thermostability carrier since it is more heat-conducting and softer (heat conductivity of graphite is 0.57 cal/g-cm-sec compared with 0.02 cal/g-cm-sec for silicon carbide) while silicon carbide is the carrier of high-temperature strength and hardness. The high covalent bonding strength of the atoms of silicon carbide (283 kcal/mole) accounts for its high decomposition temperature (above 2500 degrees C) (without melting) and hardness. This composite is obtained by means of thermochemical treatment of porous graphite with silicon in both liquid and gaseous states. In such a composite the positive properties of phase components (high oxidation resistance of SiC, high thermostability of graphite) can be combined while their negative properties (low thermostability of SiC, low hardness and strength of graphite) can be to some extent neutralized. Author (TAB)

N70-14462/ North Carolina State Univ., Raleigh. Dept. of Materials Engineering.

DEVELOPMENT OF HIGH TEMPERATURE MATERIALS FOR SOLID PROPELLANT ROCKET NOZZLE APPLICATIONS
Quarterly Progress Report, 1 Jul.-30 Sep. 1969

Charles R. Manning, Jr. and Lynn D. Linebeck 1 Oct. 1969 17 p
(Grant NGR-34-002-108)

(NASA-CR-107-354; QPR-1) Avail: CFSTI CSCL 11D

Preliminary work is described in the development of a refractory metal and/or graphite composite with a ceramic base having resistance to mechanical and chemical erosion and thermal shock. The composite must demonstrate these properties in the rocket nozzle throat area where the environmental stresses are most severe. Tasks completed include: the acquisition of information on equipment and supplies; the design and construction of custom equipment and installation; a literature survey on the proposed composites; and, the establishment of standard tests and other procedures for composite and input material evaluation. M.H.E.

N70-14476/ Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
GRAPHITIZED MATERIALS

V. P. Sosedov et al 7 Apr. 1969 17 p Transl. into ENGLISH from Khim. Tverd. Topl (Moscow), no 2, 1958 p 91-98
(AD-695030; FTD-MT-24-482-68) Avail: CFSTI CSCL 11/7

The development of the Soviet industry of graphitized materials and of the present state-of-the-art is reviewed. The important technical properties of the materials, the production, the availability of raw materials and the modern trend in the R and D are discussed. Combinations of graphitized material with other elements, such as silicon, boron, some metals, and with synthetic resins are mentioned. The level of the production of graphitized materials is indicative of the industrial potential of country; the Soviet industry of these materials has reached the world level now. The history of this development is told briefly in the post-war decades. Author (TAB)

From CAB

4337 Refractory Materials Versus High-Velocity Atmospheric-Flight Conditions

The response of refractory materials to oxidation in air over a wide range of time, gas velocity, temperature, and pressure has been studied in a multidisciplinary program conducted by ManLabs for the Air Force (AFML). The study spans the heat flux and boundary-layer-shear spectrum of conditions encountered during high-velocity atmospheric flight, as well as conditions normally employed in materials-oriented investigations. Efforts were made to elucidate the relationship between hot-gas/cold-wall (HG/CW) and cold-gas/hot-wall (CG/HW) surface effects in terms of heat- and mass-transfer rates at high temperatures, so that full use could be made of both types of experimental data.

Exposures of specimens in HG/CW tests were performed in AVCO facilities which provided stagnation pressures between 0.002 and 4.0 atmospheres, stagnation enthalpy between 2000 and 16,000 Btu/lb, cold-wall heat flux between 100 and 1500 Btu/ft² sec, and exposure times between 20 and 23,000 seconds. Exposure tests also were conducted in the Cornell Wave Superheater which provided heat flux leads up to 8000 Btu/ft² sec at very high gas velocity for short time. The CG/HW tests included (1) specimens heated in furnace with air flowing at 0.9 to 9.0 ft/sec for times from 5 minutes to 4 hours, (2) specimens heated by induction in oxygen-helium mixtures at flow rates of 0.2 ft/sec and oxygen partial pressures of 0.013 to 0.20 atmosphere for times up to four hours, and (3) specimens heated inductively (2000-4500 F) with air-flow rates between 10 and 300 ft/sec for times up to 1 hour.

The materials evaluated in the program are listed in Table 4337-1.

TABLE 4337-1. REFRACTORY MATERIALS EVALUATED

Boride Materials	Carbon Materials	
HfB _{2.1}	RVA	
ZrB ₂	PG	
HfB ₂ + 20 v/o SiC	BPG	
Boride Z		
HfB _{2.1}	PT 0178	
HfB _{2.1} + 20 v/o SiC	POCO (AXF-5Q)	
ZrB _{2.1} + 20 v/o SiC	Glassy Carbon	
HfB _{2.1} + 35 v/o SiC	JTA	
ZrB ₂ + 14 v/o SiC + 3 v/o C	JT 0992	
	JT 0981	
Carbide Materials	Coated Materials	
HfC + C	Si/graphite	
ZrC + C	Ir/graphite	
	Sn-Al/Ta-W	
	WSi ₂ /W	
Oxide Materials	Metallic Alloys	
SiO ₂ + 68.5 w/o W	Hf-20Ta-2Mo	Ir-Pt
SiO ₂ + 60 w/o W	W-Ag	Ir-Rh
SiO ₂ + 35 w/o W	W-Zr-Cu	Ir-Re
	Ir	Ir-Os

Pretest material characterization and posttest examination were made on the candidate materials. The specimens ranged from 0.5 to 1.5 inch in diameter.

Some of the major accomplishments of the program include:

- (1) Delineation of the altitude velocity/flux-enthalpy comparison for refractory materials
- (2) Demonstration of the reuse capabilities of boride composites for multimission lifting reentry trajectories
- (3) Identification of the minimum oxide temperature limit criteria for HG/CW performance
- (4) Measurement of temperature gradients through oxide films during HG/CW and high-velocity CG/HW tests
- (5) Calculation of temperature gradients through oxide films in HG/CW tests
- (6) Specification of low-temperature failures in refractory materials
- (7) Effects of pressure on the oxidation behavior of refractory materials
- (8) Observations of thermal-stress failures
- (9) Effects of sample orientation on the thermal-stress resistance of hot-pressed materials
- (10) Measurement of spectral and total normal emittance under oxidizing conditions
- (11) Prediction of model surface temperature from stream conditions
- (12) Prediction of 1 to 3-mil-per-second-boundary based on melting
- (13) Effects of cyclic exposure under oxidizing conditions
- (14) Effects of alloying and oxide additions on the oxidation of iridium alloys
- (15) Influence of sample geometry and air-flow rate on graphite oxidation kinetics

- (16) Influence of calorimeter and shroud size and shape on the measured heat flux
- (17) Formulation and programming of generalized surface-reaction problem
- (18) Calculation of graphite ablation rates.

Details of the program and results obtained are covered in the various reports listed below:

Stability Characterization of Refractory Materials Under High Velocity Atmospheric Flight Conditions, AFML-TR-69-84, ManLabs, Inc., Contract No. AF 33(615) 3859:

Part I, Volume I, "Summary", L. Kaufman and H. Nesor (March, 1970) (83 pages, 7 tables, 47 figures).

Part II, Volume I, "Facilities and Techniques Employed for Characterization of Candidate Materials", L. Kaufman and H. Nesor (December, 1968) (86 pages, 23 tables, 68 figures) AD 865 317.

Part II, Volume II, "Facilities and Techniques Employed for Cold Gas/Hot Wall Tests", L. Kaufman and H. Nesor (December, 1969) (55 pages, 2 tables, 41 figures) AD 864 968.

Part II, Volume III, "Facilities and Techniques Employed for Hot Gas/Cold Wall Tests", L. Kaufman and H. Nesor (December, 1969) (122 pages, 10 tables, 78 figures) AD 865 316.

Part III, Volume I, "Experimental Results of Low Velocity Cold Gas/Hot Wall Tests", L. Kaufman and H. Nesor (December, 1969) (118 pages, 19 tables, 103 figures) AD 865 319.

Part III, Volume II, "Experimental Results of High Velocity Cold Gas/Hot Wall Tests", R. Perkins (Lockheed Missile/Space Company), L. Kaufman and H. Nesor (December, 1969) (125 pages, 17 tables, 82 figures) AD 865 323.

Part III, Volume III, "Experimental Results of High Velocity Hot Gas/Cold Wall Tests", L. Kaufman and H. Nesor (February, 1970) (336 pages, 39 tables, 349 figures).

Part IV, Volume I, "Theoretical Correlation of Material Performance with Stream Conditions", L. Kaufman, H. Nesor, H. Bernstein, and J. R. Baron (December, 1969) (115 pages, 28 tables, 48 figures).

Part IV, Volume II, "Calculation of the General Surface Reaction Problem", H. Bernstein and J. R. Baron (December, 1969) (144 pages, 22 tables, 23 figures).

Part V, Volume I (Additional Materials Evaluations), not yet released.

4337-6 **Materials for High-Velocity Atmospheric Flight**

An extensive progress report by Manlabs gives the results of oxidation studies of refractory borides, graphites and JT composites, hypereutectic carbide-graphite composites, refractory metals, coated refractory metals, metal-oxide composites, and coated graphites in air over the wide range of conditions encountered during reentry or high-velocity atmospheric flight as well as those employed in conventional furnace tests. Elucidation of the relationship between hot gas/cold wall (HG/CW) and cold gas/hot wall (CG/HW) surface effects in terms of heat- and mass-transfer rates is a principal goal of the program.

Procurement and characterization of thirty-one candidate materials was effected. Furnace oxidation results in flowing air at 0.9 to 7.2 ft/sec for times up to four hours between 1150 and 4200 F are presented. Temperature limits for coated materials, viscous flow of metal-oxide composites and effects of cyclic exposures are reported. Results are reported for exposures in flowing argon between 3000 and 4200 F. High velocity CG/HW exposures have been performed for graphites and selected solid oxide formers between 2500 and 4000 F. Temperature gradients up to 800 F were observed to exist through thin oxide scales. Gradients influence behavior favorably where gas/oxide or oxide/substrate temperatures limit reaction rates. Accelerated oxidation was observed for a number of candidate materials substantially below their maximum application temperature. Spectral emittance measurements are reported under oxidizing conditions between 2000 and 4000 F.

Arc-plasma exposures have been performed at Mach Numbers between 0.1 and 3.2, stagnation pressures between 0.01 and 1.0 atm., stagnation enthalpies up to 16,000 Btu/lb, cold wall heat flux up to 1200 Btu/ft² sec, exposure times up to 1800 seconds and surface

temperatures between 2100 and 6500 F. Data include material recession, metallographic and X-ray analysis, radiated heat flux, and normal total emittance. In addition, color motion picture coverage was provided. Materials forming solid oxides show lower recessions in the HG/CW tests at a stated surface temperature than in CG/HW tests. The reverse is true for ablating materials. Temperature gradients of 800 to 1500 F through 30-50 mil oxides are observed. Surface temperatures calculated from stream conditions and radiation equilibrium agree with observed temperatures on melting. When solid coatings are present, substrate surface temperatures are below computed values. Materials bearing silicon carbide achieve temperatures lower than predicted from stream conditions, and exhibit superior behavior.

Translation of the flux-enthalpy description into equivalent altitude-velocity characteristics permits comparison of stagnation point performance with relevant trajectories. Materials ranking at a stagnation point pressure of 1 atm, on this basis identifies the superiority of SiC and composites containing SiC. The widest range of applicability is afforded by the HfB_2 + SiC composite. The trajectory of the Flight Dynamics Laboratory FDL-7MC lifting reentry vehicle ($L/D = 2.5-3.0$) has been compared with the flux-enthalpy behavior of candidate materials. Several boride composites appear to satisfy the stability requirements for reuse. A kinetic description of graphite oxidation is presented covering the low and high velocity regimes. Analytical models for predicting the flux-enthalpy boundary for degradation via melting and predicting surface temperature from stream conditions including conduction and side radiation losses are presented. Numerical solutions for graphite oxidation have been obtained with a modified program for surface temperatures between 1500 and 5500 R at pressures between 0.0585 to 5.85 atm. for body radii between 0.01 and 1.0 ft. The transitions from "reaction" to "diffusion" limited behavior obtained with three different kinetic descriptions indicate the existence of an intermediate plateau.

Stability Characterization of Refractory Materials Under High-Velocity Atmospheric Flight Conditions, Progress Report No. 5, L. Kaufman and H. Nestor, Manlabs, Inc., Contract No. AF 33(615)-3859 (February, 1969) (331 pages, 183 figures, 61 tables).

6505

NbC-Graphite Composites With Low Linear Thermal Expansion

In general, NbC-graphite composites have had linear thermal-expansion coefficients (α) that are characteristic of the NbC ($8.8 \times 10^{-6} \text{ C}^{-1}$) instead of the less expansive graphite ($\alpha = 5.0 \times 10^{-6} \text{ C}^{-1}$). To produce composites with α 's that take advantage of the lower graphite expansivity, the Donald W. Douglas Laboratories have undertaken a program in which the graphite is in the form of relatively long fibers instead of acicular graphite powders, the more commonly used form.

Data were obtained on five NbC-graphite billets prepared by vacuum hot pressing at 3100 C and 3000 psi for 20 min. Three billets used chopped Thornel-50 fibers for the graphite and two used NbC-coated Thornel-50 yarn. Densities achieved ranged from 90 to 96.7 percent of theoretical.

The principal results are given in Table 6505-I. Besides mean α , the results for flexural strength, compressive creep, tensile strength and dynamic modulus are also given. In most cases, particularly with the chopped-fiber composites, the goal of lower linear thermal expansion without loss of other desirable properties was achieved. All billets show a mean α significantly lower than that of NbC, and, with the yarns, below the mean α for graphite.

Preliminary thermal-shock tests showed promising results. Metallography results indicate that improvements in homogeneity and bonding are required for maximum properties.

Low Linear Thermal Expansion NbC-Graphite Composite Studies, J. O. Gibson, Donald W. Douglas Laboratories, MDC G1662, Contract No. SNPC-67 (October, 1969) (91 pages, 10 tables, 59 figures).

6512

Particle Size and Type of Carbon in Carbide-Carbon Composites

The Materials Technology Group at Los Alamos has investigated the effects of carbon and/or graphite starting materials in the production of hot-pressed carbon-carbide composites. For the carbide-phase 46 v/o of solid solution 50-50 w/o TaC-NbC was used.

The results with graphite powder of three particle sizes, a glassy carbon powder, and a carbon black powder all indicate that graphite or carbon type and size must both be considered when trying to tailor a composite toward a particular requirement. For example, as Type 1008 graphite particle size in the composite decreases from minus 150 plus 325 mesh to $0.6\ \mu$ the thermal-shock rating increases from 360 to almost 390 with the grain, and from 355 to about 385 across the grain. Further, elastic modulus decreases with the same decreasing particle size from over 11×10^6 psi to about 3.1×10^6 psi. For the same particle size, the elastic modulus across the grain decreases from about 7.3×10^6 psi for the graphite-carbide composite to about 6.7×10^6 psi for the glassy carbon-carbide composite. Strength, electrical resistivity and dynamic modulus are also affected by starting material type and particle size.

Effect of Graphite Type and Particle Size on the Mechanical, Physical and Thermal Stress Properties of Hot-Pressed Carbide-Graphite Composites, R. E. Riley, Los Alamos Scientific Laboratory, presented at the 16th Meeting of the Refractory Composites Working Group, Seattle, Washington (October, 1969) (14 pages, 9 figures).

Metal-Matrix Composites

From IAA

A67-18441 *

CONTROL OF COMPOSITE MICROSTRUCTURE THROUGH THE USE OF COATED FILAMENTS.

S. W. Porompa, D. E. Niesz, J. N. Fleck, and C. W. Kistler, Jr. (Battelle Memorial Institute, Columbus, Ohio).

American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 5th, New York, N.Y., Jan. 23-26, 1967, Paper 67-175, 12 p., 5 refs.

Members, \$0.75; nonmembers, \$1.50.

Contract No. N0W-65-0015-c.

Coated filaments were used as the basic element to fabricate dense composites with uniform microstructures. Graphite-felt/electroless nickel, graphite-yarn/electroless nickel, Thornei-yarn/electroless nickel, Thornei-yarn/electroless cobalt, and boron-titanium were processed into shapes by hot isostatic pressing. Electroless-coated and densified structures containing up to 75 vol% reinforcement resulted in uniform interfiber spacings with a minimum of fiber-to-fiber contact. Boron-fiber-reinforced titanium composites containing from 9 to 20 vol% boron were fabricated from powder-coated fibers. This produced dense structures, in which fiber separation was maintained and reaction between boron and titanium was avoided. The strengthening provided by the boron ranged from 65 to 93% of theoretical and modulus values approximated the law of mixtures. (Author)

considered: (1) reinforcement, in which the high strength-modulus filament is incorporated for the purpose of strengthening the metal and (2) binder, in which the metal is incorporated for the purpose of binding together large volume percentages of filament. To provide a further introductory review, current problems in the areas of filament characterization, micromechanics, preparation approaches, filament-matrix interactions, and composite testing will be covered and illustrated, primarily with recent results from the authors' laboratory. (Author)

A67-37953

RECENT ADVANCES IN COMPOSITE TECHNOLOGY.

Lee R. Standifer (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Wright-Patterson AFB, Ohio).

(Deutsche Gesellschaft für Metallkunde, Hauptversammlung, Cologne, West Germany, May 17, 1967, Vortrag.)

Zeitschrift für Metallkunde, vol. 58, Aug. 1967, p. 512-524, 29 refs.

Review of recent progress in composite technology with primary emphasis on fiber-reinforced metal matrix composites. A brief discussion of the development of high-strength, high-modulus, low-density filaments is included. Current efforts on plastic and ceramic matrix composites are considered for comparative purposes. Filament-matrix interaction is considered as a major limiting factor in high-temperature fabrication and utilization of the metal matrix. Possible approaches to the solution of the problem are discussed. Fabrication methods are reviewed. The mechanical behavior of metal matrix systems is illustrated with a boron-reinforced aluminum composite. The approach taken to expedite the development of advanced composites as practical engineering structures has been to integrate the efforts of materials engineers, designers, and fabricators into a single team effort. This approach is illustrated by following the development of several fiber-reinforced-plastic aerospace structures. P.v.T.

A67-18657

METAL MATRIX COMPOSITE MATERIALS.

H. M. Burte (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Metals and Ceramics Div., Wright-Patterson AFB, Ohio), F. R. Penazzo, and J. A. Herzog (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Advanced Metallurgical Studies Branch, Wright-Patterson AFB, Ohio).

IN: ORIENTATION EFFECTS IN THE MECHANICAL BEHAVIOR OF ANISOTROPIC STRUCTURAL MATERIALS; SYMPOSIUM

PRESENTED AT THE AMERICAN SOCIETY FOR TESTING AND MATERIALS, PACIFIC AREA NATIONAL MEETING, 5TH, SEATTLE, WASH., OCTOBER 31-NOVEMBER 5, 1965. PAPERS, [A67-18653-06-12]

Symposium sponsored by the Division of Materials Sciences of the American Society for Testing and Materials. Philadelphia, American Society for Testing and Materials (ASTM Special Technical Publication No. 405), 1966, p. 59-91; Discussion, R. E. Horton (Boeing Co., Seattle, Wash.) and R. B. Clapper (NASA, Ames Research Center, Moffett Field, Calif.), p. 92, 27 refs.

A review of the potential of metal matrix composites and of currently active research is presented, also giving reasons for the recent acceleration of interest in this area. Two approaches are

A67-42475 **

REFRACTORY METAL FIBER NICKEL ALLOY COMPOSITES FOR USE AT HIGH TEMPERATURES.

Donald W. Petrusek, Robert A. Signorelli, and John W. Weeton (NASA, Lewis Research Center, Cleveland, Ohio).

Society of Aerospace Material and Process Engineers, National Symposium, 12th, Anaheim, Calif., Oct. 10-12, 1967, Paper, 50 p., 11 refs.

Evaluation of the stress-rupture properties of composites containing various combinations of refractory-metal fibers and nickel-base alloys at temperatures of 2000 and 2200°F. The effect of wire size, volume-fraction fiber content, and the composition of the matrix and fiber on the stress-rupture properties of the composite is determined. The 100-hr creep-rupture strength obtained for the best composites tested at 2000 and 2200°F was 35,000 and 14,000 psi, respectively. Stronger composites were produced with matrix materials which reacted less with the fibers than with those which were less compatible with the fibers. The presence of titanium and aluminum additions in the nickel alloys increased their compatibility with the fibers. Fiber composition also influenced the compatibility, as did the fiber diameter. Small-diameter fibers are more advantageous for short-term creep-rupture applications, while large-diameter fibers are superior for long-term applications. T.M.

A68-13189**COMPATIBILITY CONSIDERATIONS FOR METAL-MATRIX COMPOSITES.**

W. A. Compton and K. P. Steward (International Harvester Co., Solar Div., San Diego, Calif.).
 Society of Automotive Engineers, Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., Oct. 2-6, 1967, Paper 670822, 10 p. 8 refs.
 Members, \$0.75; nonmembers, \$1.50.
 Contract No. AF 33(615)-5189.

Discussion of the chemical, elastic-strain, physical-property, and manufacturing-process compatibility of metal-matrix composites. Diffusion bonding is seen to give the highest performance in the composites evaluated, although it introduced problems of physical and chemical incompatibility. Filament-area ratio control is also important in achieving optimum performance from composites. Asymmetrical elastic properties introduced by residual stresses or area-ratio variation appears to be the most difficult characteristic to appraise for any new composite. B.B.

A68-13201**METAL-MATRIX COMPOSITES BEHAVIOR AND AEROSPACE APPLICATIONS.**

H. Shimizu, J. F. Dolowy, Jr., R. J. Taylor, and B. A. Webb (Marquardt Corp., Van Nuys, Calif.).
 Society of Automotive Engineers, Aeronautic and Space Engineering and Manufacturing Meeting, Los Angeles, Calif., Oct. 2-6, 1967, Paper 670861, 9 p. 5 refs.
 Members, \$0.75; nonmembers, \$1.50.

Metal-matrix composites of aluminum, titanium, nickel, and their alloys reinforced by continuous filaments of boron or silicon carbide are considered. The aluminum-boron system provides advantages at temperatures to 600°F for general application, and the titanium-silicon carbide system shows promise for high-temperature applications, but the nickel-silicon carbide matrix presents problems in the reaction between the two metals at high temperatures. Selection of matrix alloys depends on filament loading, thermal history imposed by fabrication and usage requirements, the composite reinforcement geometry, and the nature of stress distribution resulting from external loadings. (Author)

A68-16772**ELECTROFORMING TO MAKE COMPOSITE MATERIALS.**

N. R. Adsit (General Dynamics Corp., Convair Div., San Diego, Calif.).

IN: FIBER-STRENGTHENED METALLIC COMPOSITES; AMERICAN SOCIETY FOR METALS, METALS CONGRESS, SYMPOSIUM, CHICAGO, ILL., NOVEMBER 2, 3, 1966, PAPERS. [A68-16770 05-17]

Symposium sponsored by the American Society for Testing and Materials, and the American Society of Mechanical Engineers. Philadelphia, Pa., American Society for Testing and Materials (ASTM Special Technical Publication No. 427), 1967, p. 27-33.

Investigation of the production of composite materials by electroforming. This is potentially a very useful method, since it makes it possible to form completed parts and to bypass several fabrication steps. The materials investigated include boron and carbon filaments in nickel, copper, and aluminum matrices. A nickel-sulfamate bath was used for plating nickel and an aluminum-ether bath for plating aluminum. The results indicate that the strength of the boron in nickel composite material obeys the law of mixtures. There may be a loss of adhesion at very close spacing of the filaments, however. Results of annealed nickel with boron filaments indicate that a NiB layer is formed, and the kinetics of the reaction were investigated. Preliminary results are given concerning the fatigue and toughness properties of the nickel-boron composites. It is concluded that the electroforming process shows promise for producing boron-nickel, boron-aluminum, and carbon-nickel composites. M.M.

A68-16774**FUNDAMENTAL STUDY OF METAL MATRIX COMPOSITES.**

W. T. Marzella, W. S. Margolis, and H. R. Thornton (General Dynamics Corp., Fort Worth Div., Fort Worth, Tex.).

IN: FIBER-STRENGTHENED METALLIC COMPOSITES; AMERICAN SOCIETY FOR METALS, METALS CONGRESS, SYMPOSIUM, CHICAGO, ILL., NOVEMBER 2, 3, 1966, PAPERS. [A68-16770 05-17]

Symposium sponsored by the American Society for Testing and Materials, and the American Society of Mechanical Engineers. Philadelphia, Pa., American Society for Testing and Materials (ASTM Special Technical Publication No. 427), 1967, p. 53-68. 5 refs.

Discussion of an experimental investigation of certain fundamental factors governing the strength of filament-reinforced metal matrix composites. The matrix candidates were aluminum, copper, magnesium, nickel, and titanium. The filament candidates were boron, molybdenum, and steel. Three test specimen configurations for the evaluation of the effects of filament-to-matrix reactions in composite structures were developed and verified. Preliminary data are presented for various filament-matrix combinations. Data are included on the effects of the fabrication process, filament surface preparation, filament overlap distance, filament spacing, and filament diameter. (Author)

A68-16775**HOW METAL MATRIX COMPOSITES ARE MADE.**

L. W. Davis (Harvey Aluminum, Inc., Harvey Engineering Laboratories, Torrance, Calif.).

IN: FIBER-STRENGTHENED METALLIC COMPOSITES; AMERICAN SOCIETY FOR METALS, METALS CONGRESS, SYMPOSIUM, CHICAGO, ILL., NOVEMBER 2, 3, 1966, PAPERS. [A68-16770 05-17]

Symposium sponsored by the American Society for Testing and Materials, and the American Society of Mechanical Engineers. Philadelphia, Pa., American Society for Testing and Materials (ASTM Special Technical Publication No. 427), 1967, p. 69-90. 14 refs.

Discussion of methods employing metal matrices to achieve distribution of the reinforcement in the matrix. These methods include powder metallurgy, electrodeposition, plasma flame spraying molten-metal impregnation, and solid-state diffusion bonding. Emphasis is placed on two methods, namely diffusion bonding for building up the matrix around continuous fibers and molten-metal encapsulation with whiskers. Most of the work has been done in the development of an aluminum-matrix composite with continuous fine-steel wire as the reinforcing material. A number of compositions have been employed, but type 355 stainless-steel wire in 2024 aluminum alloy has had most use. Heat, pressure, plastic deformation and coatings have been used in various combinations for bonding the steel wire in the aluminum matrix. Tests have been made to determine the feasibility of incorporating brittle reinforcing materials, such as beryllium and boron, in the aluminum matrix. M.M.

A68-16777**HIGH ENERGY-RATE FORMING OF FIBROUS COMPOSITES.**

R. K. Robinson (Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Wash.).

IN: FIBER-STRENGTHENED METALLIC COMPOSITES; AMERICAN SOCIETY FOR METALS, METALS CONGRESS, SYMPOSIUM, CHICAGO, ILL., NOVEMBER 2, 3, 1966, PAPERS. [A68-16770 05-17]

Symposium sponsored by the American Society for Testing and Materials, and the American Society of Mechanical Engineers. Philadelphia, Pa., American Society for Testing and Materials (ASTM Special Technical Publication No. 427), 1967, p. 107-123. 5 refs.

Research sponsored by the Battelle Memorial Institute; AEC Contract No. AT (45-1)-1830.

Fabrication problems with metal matrix composite materials include compatibility of the matrix and reinforcement, retention of fiber alignment, and formation of intricate shapes or structures. Preliminary studies of 11 composite systems were made using a pneumatic-mechanical high energy-rate forming process. Compatibility problems were reduced by the use of temperatures lower than those used in more conventional processes. Alignment retention appeared to be controllable by varying the impaction mold design to produce preferential axial, radial, or isostatic forces. The forming method was highly effective for the formation of complex monolithic structures such as turbine blades, honeycombs, and nozzles having internal cooling passages. (Author)

A68-24290 ***CARBON-FILAMENT-REINFORCED COBALT AND NICKEL.**

D. E. Niesz, J. N. Flock, C. W. Kistler, Jr. (Battelle Memorial Institute, Columbus Laboratories, Columbus, Ohio), and L. Machlin (U.S. Naval Air Systems Command, Washington, D.C.).

American Institute of Aeronautics and Astronautics, and American Society of Mechanical Engineers, Structures, Structural Dynamics and Materials Conference, 9th, Palm Springs, Calif., Apr. 1-5, 1968, AIAA Paper 68-338, 13 p. 15 refs.

Members, \$1.00; nonmembers, \$1.50.

Review of the high-temperature material requirements for advanced turbines and discussion of the potential payoff of filament-reinforced metals over currently available materials. The results of an experimental program to develop and evaluate carbon-filament-reinforced cobalt and nickel for these applications are then presented. Evaluation samples were fabricated by hot isostatically pressing bundles of metal-coated carbon filaments. Microstructural evaluation showed uniform filament spacings. Stability of this microstructure after exposure for 100 hr at 1832°F in nitrogen was demonstrated. Mechanical-property data showed that the ultimate tensile strength of the experimental material was less than 50% of the theoretical strength as calculated for a simple continuous-filament model. These low strengths were attributed to filament breakage during fabrication. This problem has been eliminated in subsequent research. The research required to complete the development and evaluation of these materials for high-temperature structural applications is discussed. (Author)

A68-25708**RECRYSTALLIZATION OF NICKEL-COATED CARBON FIBRES.**

P. W. Jackson and J. R. Marjoram (Rolls-Royce, Ltd., Composite Materials Research Dept., Derby, England).

Nature, vol. 218, Apr. 6, 1968, p. 83, 84. 5 refs.

Investigation of carbon fibers carbonized by controlled pyrolysis of polymer fiber up to 1000°C, and of those graphitized by further treatment up to 2700°C. Both types of fiber seemed to have recrystallized during heat treatment to attain extensive three-dimensional order and increased crystallite size. The appearance of graphite diffraction arcs associated with three-dimensional order and improved line sharpness are demonstrated. M.G.

A68-41767**FRICTION AND WEAR PROPERTIES OF CARBON FIBRE-REINFORCED METALS.**

J. P. Giltrow and J. K. Lancaster (Ministry of Technology, Royal Aircraft Establishment, Materials Dept., Farnborough, Hants., England).

Wear, vol. 12, Aug. 1968, p. 91-105. 13 refs.

Description of some methods for preparing composites of metal and carbon fibers, and examination of their friction and wear properties at various temperatures up to 470°C. Composites of randomly oriented, chopped carbon fibers in Pb, Ag, Cu, Ni, and Co are prepared by powder-metallurgical techniques, with fiber contents up to 25 vol%. The most satisfactory method of fabrication is hot pressing of fibers precoated with metal by electroless deposition. Rates of wear of the composites, measured at room temperature during sliding against tool steel with and without lubrication, are appreciably lower than those of the parent metals. The coefficients of friction are not reduced, however, nor are the wear rates at elevated temperatures (470°C). It is concluded that the carbon fibers function by facilitating the development of a strengthened surface layer during sliding. The fibers do not appear to improve the bulk mechanical properties, and possible reasons for this are discussed. Z. W.

A69-18236**CARBON FIBRES.**

W. T. Gunston.

Science Journal, vol. 5, Feb. 1969, p. 39-49. 7 refs.

Description of the development of high-strength carbon fibers, their applications as reinforced composite materials, and possible applications in the aerospace industry. Batch production and continuous production of carbon-fiber reinforced composites are described. The use of these composites is illustrated by an example of a turbine blade for a turbofan engine. Possible applications in aircraft design

are also discussed. The use of carbon fibers in a metal matrix is examined. A review of possible applications of carbon-fiber reinforced composites in hydrology, and in the construction of pressure vessels, electrical cables, and prostheses is presented. Z. W.

A70-20048**COMPATIBILITY STUDIES OF CARBON FIBRES WITH NICKEL AND COBALT.**

P. W. Jackson and J. R. Marjoram (Rolls-Royce, Ltd., Advanced Research Laboratory, Derby, England).

Journal of Materials Science, vol. 5, Jan. 1970, p. 9-23. 25 refs.

Techniques have been evolved to study the compatibility of single carbon fibers coated with nickel or cobalt, and the results have been shown to be applicable to bulk composites. Carbon fibers undergo structural recrystallization in contact with the nickel or cobalt matrix by a dissolution/diffusion/precipitation mechanism. The effective activation energy for this recrystallization process approximates that for carbon diffusion in nickel or cobalt. (Author)

From STAR

N65-27680* # National Aeronautics and Space Administration, Washington, D.C.

PROPERTIES OF COMPOSITE MATERIALS, REINFORCED BY TRICHITE FILAMENTS (WHISKERS) [LES PROPRIETES DES MATERIAUX COMPOSITES RENFORCES PAR LES FILAMENTS DE TRICHITES (WHISKERS)] H. de l'Estoule May 1965 16 p refs Transl. into ENGLISH from Doc-Air-Espace (France), no. 90, 1965 p 19-24 (NASA-TT-F-9372) CFSTI: HC \$1.00/MF \$0.50 CSCL 11D

A brief review is given over properties of composite materials, reinforced by whiskers formed of filaments of graphite, iron, silver, copper, quartz, zinc, cadmium, and aluminum oxide, with tabulation of their mechanical properties and stress-strain diagrams. The ultimate strength, at various stresses and strains, is calculated for a typical example of aluminum whiskers forming 50 vol.% in titanium-molybdenum alloys, certain steels, and columbium alloys. The use of a René 41 steel, reinforced with 50% of aluminum whiskers, will reduce the weight at a ratio of 4 to 1 in the construction of a pressurized enclosure, provided that the whiskers are oriented in accordance with the isotenoid. A composite material with 12 vol.% oriented aluminum whiskers will be about 10 times stronger than a nonreinforced light alloy. Author

N66-34367* # Southwest Research Inst., San Antonio, Tex. NON-GLASSY INORGANIC FIBERS AND COMPOSITES

Cameron G. Harman Washington, NASA, Aug. 1966 44 p refs Sponsored by NASA

(NASA-SP-5055) GPO: HC \$0.35; CFSTI: MF \$0.50 CSCL 13H

General summaries of NASA-generated and related information dealing with fibers, filaments, and composites are presented in a review of Non-glassy Inorganic Fibers and Composites. Concept and theory of fiber-reinforced composites is discussed, as are whiskers, polycrystalline fibers, and metal wires. Attention is given to boron carbide whiskers, boron filaments, and refractory ceramic fibers. Among the metal-fiber-reinforced metallic composites considered are: (1) copper reinforced with tungsten fiber, (2) boron-aluminum composites, (3) boron-magnesium composites, and (4) composites with *in situ* fibering. Organic and glass fibers, as well as composites with organic matrices are included. M W R.

From CAB

6782 Metal Diboride Matrix Composites

Union Carbide personnel have been investigating the processing techniques for the fabrication of thermodynamically stable and structurally sound Thornei fiber-reinforced composites having matrices of TiB_2 and ZrB_2 . The three principal tasks of the program are:

- Task I Develop compatible refractory coatings for "Thornei" 50 fibers by the chemical-vapor-deposition technique
- Task II Fabricate TiB_2 - "Thornei" and ZrB_2 - "Thornei" composites by conventional hot-pressing techniques
- Task III Conduct exploratory experiments using high-strength fibers other than "Thornei".

The fiber-coating work was performed in a hot-yarn, chemical vapor deposition (CVD) apparatus designed to coat the fibers in a continuous process. Considerable difficulties were experienced in producing a uniform CVD coating of TiC on Thornei fiber bundles. Although the outer fibers in the bundle were coated with TiC , the coating on the inner fibers was primarily pyrolytic carbon.

Fabrication experiments were performed on TiB_2 -Thornei 50 composites, TiB_2 - SiC -Thornei 50 composites, and TiB_2 - SiC composites containing coated Thornei 50 fibers. Uniform, random dispersions of chopped (1/4 inch length) Thornei 50 fibers were achieved in the composites (20 volume percent fiber) using a slip-casting technique. Slip-cast preforms were hot pressed at 8000 psi at temperatures from 1700 to 2100 C. Hot pressing at 2000 and 2100 C produced a fully dense composite but degradation (recrystallization) of the Thornei fiber occurred at these temperatures.

The extent of fiber degradation in composites prepared with coated fibers was judged less severe, although it is acknowledged that improved coatings are needed before a valid assessment of the effectiveness of the coating in retarding fiber degradation can be made.

Research Program on Transition Metal Diboride Matrix Composites, H. F. Volk and D. A. Schulz, Union Carbide Corporation, Parma Technical Center, Technical Management Report No. 1, Contract No. F33615-69-C-1645 (December, 1969) (40 pages, 7 tables, 33 figures).

Author Index

- Adsit, N. R., 21
 Auerbach, I., 4
 Babel, H. W., 2
 Bacon, R., 2
 Badami, D. V., 4
 Baron, J. R., 17
 Bauer, D. W., 4
 Bernstein, H., 17
 Blum, S. L., 9, 15
 Bonanno, F. R., 20
 Boquist, C. W., 11
 Bortz, S. A., 9, 14, 15
 Brizes, W. F., 14
 Burte, H. M., 20
 Bushong, R. M., 11
 Camahan, R. D., 14
 Chalykh, Ye. F., 6
 Clougherty, E. V., 10
 Compton, W. A., 21
 Cook, J. L., 3, 6, 7
 Coyle, R. A., 15
 Davidson, K. V., 12, 13
 Davis, L. W., 21
 de l'Estoile, H., 22
 Diaconis, N. S., 5
 Dolowy, J. F., 21
 Dosser, D. M., 2
 Doyle, H. J., 4
 Eliutin, V. P., 4
 Engel, M. J., 5
 Fassell, W. M., 3
 Feingold, E., 12
 Fleck, J. N., 20, 22
 Ford, A. R., 2
 France, L. L., 1, 1
 French, L. L., 14
 Frye, E. R., 7
 Galasso, F. S., 11
 Gatti, A., 12
 Gibson, J. O., 18
 Gillin, L. M., 15
 Giltrow, J. P., 22
 Goldstein, E. M., 2
 Guess, T. R., 2
 Gunston, W. T., 22
 Harada, Y., 9, 11, 11, 11, 12, 12, 12, 13, 13, 14, 14, 14, 15
 Harman, C. G., 22
 Haviland, J. K., 1
 Hawkins, H. T., 5
 Heath, G. A., 3
 Hengstenberg, T. F., 1
 Herrick, J. W., 2
 Herzog, J. A., 20
 Higgs, P. H., 4, 5
 Jackson, P. W., 22, 22
 Jakas, R., 12
 Janowski, K. R., 14
 Jenkins, G. M., 4
 Kaarlela, W. T., 21
 Kachur, V., 1, 1
 Kaufman, L., 10, 17, 18
 Kawamura, K., 4
 Kendall, E. G., 9
 Kistler, C. W., 20, 22
 Kostikov, V. I., 4
 King, R. W., 2
 Lafyatis, P. G., 5
 Lambdin, F., 3, 6, 7
 Lancaster, J. K., 22
 Lee, L. M., 2
 Leeds, D. H., 4
 Levin, V. la., 4
 Lineback, E. D., 15
 Lumby, R. J., 3
 Lurie, R. M., 2
 MacKay, H. A., 6

BLANK PAGE

- MacLaughlin, T. F., 5
 Mancuso, C., 12
 Manning, C. R., Jr., 15
 Margolis, W. S., 21
 Marjoram, J. R., 22, 22
 May, R. P., 2
 McAllister, L. E., 2
 McBride, D. D., 4
 McHenry, R. J., 2
 McLaughlin, L. M., 7
 McVey, D. F., 4
 Medford, J. E., 1
 Metzger, J. W., 5
 Miccioli, B. R., 13
 Miller, G. H., 12
 Moss, R. G., 6
 Nestor (Nesor), H., 17, 18
 Niesz, D. E., 20, 22
 Nolan, E. J., 5, 5

 Olcott, E. L., 3

 Parmee, A. C., 3, 6
 Penton, A. P., 3
 Perkins, R., 17
 Petrusek, D. W., 20
 Porembka, S. W., 20

 Richerson, N. K., 14
 Riley, R. E., 12, 13, 14, 19
 Riley, W. C., 9
 Robinson, G. C., Jr., 12
 Robinson, J. H., 1
 Robinson, R. K., 21
 Rohl, C. W., 1
 Rossi, R. C., 14
 Rubin, G. A., 11, 13

 Schell, D. H., 14
 Schmidt, D. L., 5
 Schulz, D. A., 23
 Schutzler, J. C., 2
 Schwartz, M. A., 3, 10
 Shaver, R. G., 9, 10
 Shimizu, H., 21
 Signorelli, R. A., 20
 Slaughter, J. I., 9
 Smith, W. H., 4
 Sosedov, V. P., 15
 Spork, E., 6
 Standifer, L. R., 20
 Steward, K. P., 21
 Stoller, H. M., 7
 Stover, E. R., 7

 Tanzilli, R. A., 5, 5
 Taub, J. M., 12, 13
 Taylor, R. J., 21
 Thackray, R. W., 3
 Thornton, H. R., 21
 Tsukerman, S. A., 15

 Valeriani, A. P., 4
 Vohler, O., 6
 Volk, H. F., 23

 Webb, B. A., 21
 Weeton, J. W., 20
 Weger, E., 5
 Weng, T-L., 9, 10
 White, R. C., 9
 Whitney, J. M., 6

 Zeitsch, K. J., 4, 5
 Zorich, D. R., 3