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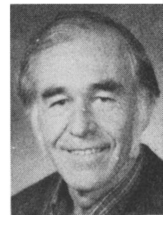
STATUS OF METALLIC MATERIALS DEVELOPMENT FOR APPLICATION IN ADVANCED HIGH-TEMPERATURE GAS-COOLED REACTORS

Hubertus Nickel
Tatsuo Kondo
Philip L. Rittenhouse

PREFACE: STATUS OF METALLIC MATERIALS DEVELOPMENT FOR APPLICATION IN ADVANCED HIGH-TEMPERATURE GAS-COOLED REACTORS



Hubertus Nickel (top) [Dr. rer. nat., chemistry and metallurgy, Technical University of Aachen, Federal Republic of Germany (FRG)] has been director of the Department for Reactor Materials in the Nuclear Research Center (KFA), Jülich, FRG. He is also a full professor for reactor materials and nuclear fuel elements at the Technical University of Aachen. In his role as a member of the German Reactor Safety Committee (since 1972), he has been involved with the safety of different reactor types, particularly the standardization of the light water reactor (LWR) as well as the realization of closing the fuel cycle for LWRs. **Tatsuo Kondo** (center) (BS, metallurgical engineering, Tohoku University; MS, 1963, and PhD, 1965, Ohio State University) has been employed at the Japan Atomic Energy Research Institute (JAERI) since 1958 and is deputy director of the fuels and materials department. He has worked in the areas of corrosion-assisted fracture of metals in reactor environments and alloy development. He presently supervises the material research programs for high-temperature gas-cooled reactors, LWRs, and nuclear fusion. **Philip L. Rittenhouse** (bottom) graduated from the University of Tennessee with an advanced degree in metallurgical engineering and has been with Oak Ridge National Laboratory (ORNL) for over 25 years. Over the past 10 years he has been associated with the program on gas-cooled reactors and during that period spent almost two years in England with the Dragon Project and High Temperature Materials Programme. He spent an additional two years with the Institut für Reaktorwerkstoff, Kernforschungsanlage Jülich in FRG. His current responsibilities at ORNL include being manager of the Gas-Cooled Reactor Materials Program and manager of the HTGR Base Technology Program.

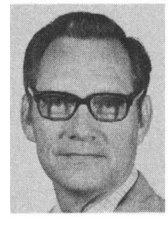
MANUFACTURE OF A HEAT-RESISTANT ALLOY WITH MODIFIED SPECIFICATIONS FOR HTGR STRUCTURAL APPLICATIONS

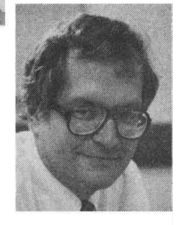
Kensho Sahira
Toshiki Takeiri
Tatsuo Kondo

Kensho Sahira (top) (BS, metallurgical engineering, University of Nagoya, 1969) has been employed at the Research Division of Mitsubishi Metal Corporation since 1969. He has been engaged in the research of alloy development and processing for high-temperature application of materials. **Toshiki Takeiri** (center) (BS, metallurgical engineering, University of Tokyo, 1964) has been employed at the Non-Ferrous Material Division of Mitsubishi Metal Corporation. He is a section manager in the engineering department of the Okegawa plant. He has been involved in the production engineering of high-temperature alloys. He has cooperated with the material development of the Japanese high-temperature gas-cooled reactor (HTGR) program for the last ten years, particularly in improvement of alloys for HTGR applications by optimization of production processes. **Tatsuo Kondo** (bottom) (BS, metallurgical engineering, Tohoku University; MS and PhD, Ohio State University, 1963 and 1965) has been employed at the Japan Atomic Energy Research Institute since 1958 and is deputy director of the fuels and materials department. He has worked in the areas of corrosion-assisted fracture of metals in reactor environments and alloy development. He currently supervises the material research programs for HTGRs, light water reactors, and nuclear fusion.

PRODUCTION AND WELDING TECHNOLOGY OF SOME HIGH-TEMPERATURE NICKEL ALLOYS IN RELATION TO THEIR PROPERTIES

T. H. Bassford
James C. Hosier

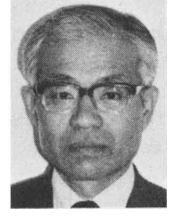




T. H. Bassford (top) (BS, mechanical engineering, Georgia Institute of Technology, 1952; MS, metallurgical engineering, University of Cincinnati, 1976) is a registered professional engineer with the State of West Virginia. He is currently the chief mechanical testing engineer for Huntington Alloys, Inc. (HA), a subsidiary of Inco Limited. Since 1952 his experience has included alloy development, mechanical and physical testing, and mill processing of nickel alloys. **James C. Hosier** (BS, metallurgical engineering, Case-Western Reserve University, 1961) is currently a senior metallurgist for HA. His experience includes alloy development and corrosion testing of materials for service in both aqueous and high-temperature gaseous environments. He is a coinventor of Inconel alloy 617.

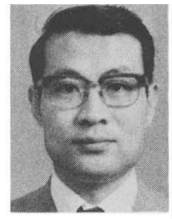
WELDABILITY AND WELD PERFORMANCE OF A SPECIAL GRADE HASTELLOY-X MODIFIED FOR HIGH-TEMPERATURE GAS-COOLED REACTORS

Shigeki Shimizu
Yasushi Mutoh



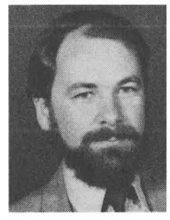
Shigeki Shimizu (right) (PhD, welding engineering, Osaka University, 1977) is a senior researcher in the Nuclear Systems Division at Kawasaki Heavy Industries Ltd. His current research interests include the study of weldability and material properties

of alloys for very high temperature reactor (VHTR) and fast breeder reactor components. **Yasushi Mutoh** (right) (Master of Technology, Tokyo University, 1967) is a senior researcher in the VHTR Designing Laboratory, Division of Power Reactor Projects at the Japan Atomic Energy Research Institute. His current research interests include the study of material properties of high-temperature alloys.



HOT EXTRUDED HIGH-TEMPERATURE ALLOY TUBES AND SOME MECHANICAL PROPERTIES

Herbert Aigner
H. Peter Degischer
Erich Hertner



Herbert Aigner (top) [Dipl.-Ing., University of Mining (UM), Leoben, 1975] works at the Austrian Vereinigte Edelstahlwerke (VEW) AG within the R&D group of the plant in Ternitz. His main interests lie in the area of high-temperature alloys, especially in precipitation strengthening and creep rupture properties. **H. Peter Degischer** (center) (Dipl.-Ing., Dr. techn., physics, Technical University of Vienna, 1971) joined the Austrian Research Center Seibersdorf (ÖFZS) in 1970. He spent three years teaching at the University of Cumaná (Venezuela). Since his return to the Institute of Metallurgy at ÖFZS, he has pursued electron metallography in high-temperature alloys, aluminum alloys, etc. **Erich Hertner** (bottom) (Dipl.-Ing., UM, 1979), assistant at the hot forming tube mill at the VEW in Ternitz, is engaged in the development of the technology for the extrusion of special alloys.

INCONEL-618E: AN ALLOY DEVELOPED FOR HIGH-TEMPERATURE GAS-COOLED REACTOR SERVICE

A. C. Lingenfelter

A. C. Lingenfelter (BS, metallurgical engineering, Case Institute of Technology, 1961; MS, metallurgy, University of Cincinnati, 1974) is senior metallurgist at Huntington Alloys, Inc., Huntington, West Virginia. Since 1961, he has been involved in welding process research, base-metal weldability studies, and alloy development.

GRAIN BOUNDARY PRECIPITATION TREATMENT FOR IMPROVING THE HIGH-TEMPERATURE LOW-CYCLE FATIGUE STRENGTH OF SSS113M FOR VHTRs

Rikizo Watanabe

Rikizo Watanabe (Dr. Eng., metallurgy, University of Tokyo, 1963) is a senior researcher in the metallurgical laboratory, Yasugi Works, Hitachi Metals, Ltd. He has worked on the R&D of superalloys, especially alloy design, for 15 years.

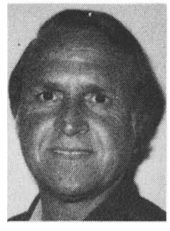
RESEARCH AND DEVELOPMENT ON HEAT-RESISTANT ALLOYS FOR NUCLEAR PROCESS HEATING IN JAPAN

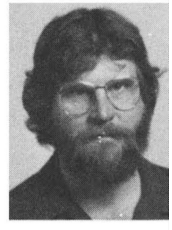
Ryohei Tanaka
Tatsuo Kondo

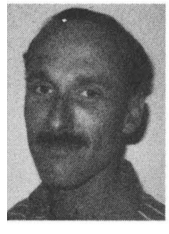
Ryohei Tanaka (top) (BS, metallurgical engineering, 1949, and Dr. Eng., 1959, Tokyo Institute of Technology) was an associate professor (1956-1965) at the Tokyo Institute of Technology and a professor (1965-1983) in the Department of Metallurgical Engineering before being appointed to his present position of professor in the Department of Materials Science in 1983. He has also been dean of students at the Tokyo Institute of Technology since 1982. His main field of interest is the physical and mechanical metallurgy of heat-resistant steels and superalloys. **Tatsuo Kondo** (BS, metallurgical engineering, Tohoku University; MS and PhD, Ohio State University, 1963 and 1965) has been employed at the Japan Atomic Energy Research Institute (JAERI) since 1958 and is deputy director of the fuels and materials department. He has worked in the areas of corrosion-assisted fracture of metals in reactor environments and alloy development. He presently supervises the material research programs for high-temperature gas-cooled reactors, LWRs, and nuclear fusion.

DESIGN OF WROUGHT NICKEL-BASE ALLOYS FOR ADVANCED HIGH-TEMPERATURE GAS-COOLED REACTOR APPLICATIONS

W. R. Johnson
L. D. Thompson
Thomas A. Lechtenberg







W. R. Johnson (top) (PhD, materials science, Stanford University, 1969) is manager, Materials Evaluation Branch, Materials and Chemistry Division, at GA Technologies, Inc. (GA). His primary interest during the past approximately 12 years has been in evaluation of effects of corrosion on the mechanical behavior of structural materials in high-temperature gas-cooled reactor (HTGR) environments with emphasis on mechanisms, thermodynamics, and kinetics of such corrosion phenomena as carburization, oxidation, and sulfidation. **L. D. Thompson** (center) [BE, metallurgical engineering, Youngstown State University; MS, 1976, and PhD, 1978, Materials Science and Engineering, University of California, Berkeley (UC-B)] is an assistant professor in the mechanical engineering department at San Diego State University. He has worked in the areas of HTGR corrosion, alloy design for HTGR structural components, and fusion reactor first-wall/blanket structural materials problems. His current interests are in the areas of alloy design for advanced turbine applications, solid-state strain-induced phase transformations, and the design and development of fail-safe emergency switches to enhance the safety of advanced energy systems. **Thomas A. Lechtenberg** (bottom) (PhD, UC-B, 1979) is a senior scientist with GA. His interests include alloy development, advanced energy for application such as first-wall/blanket structures for fusion machines, and microstructure/mechanical property relationships.

EXPERIMENTAL WORK ON ALLOY DEVELOPMENT FOR HIGH-TEMPERATURE GAS-COOLED REACTOR SYSTEMS

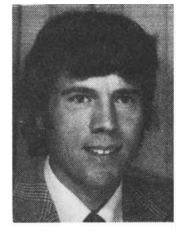
M. R. Warren

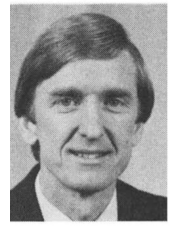
M. R. Warren (BSc, University of Birmingham, 1964; PhD, University of Birmingham, 1967; C. Eng.; M.I.M.) has been a member of the High Temperature Materials Programme Group,

working on the German Prototype Nuclear Process Heat Project, since the inception of the group in 1976. His primary interests are in the study and understanding of corrosion and mechanical properties of high-temperature commercial and model alloys being considered for use in the primary and secondary circuits of high-temperature reactors linked to process heat systems.

THE DEVELOPMENT OF HIGH-STRENGTH ALLOYS RESISTANT TO CORROSION IN IMPURE HELIUM

A. V. Dean
Philip J. Ennis

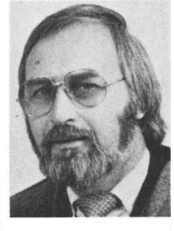


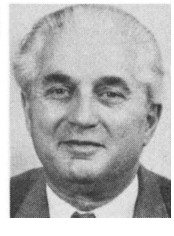


A. V. Dean (top) (BSc, metallurgy, London University) joined the National Gas Turbine Establishment in the United Kingdom in 1961, where he studied corrosion and strengthening aspects of high-temperature alloys. He joined the R&D laboratory of Inco Europe Ltd. in Birmingham in 1966, where he worked on nonferrous materials and was later responsible for the evaluation and development of alloys for the high-temperature gas-cooled reactor (HTGR). Since 1978 he has continued these studies at the Nuclear Research Centre (KFA) Jülich. **Philip J. Ennis** (BSc, physical metallurgy, University of Birmingham, United Kingdom, 1965) is a research metallurgist at the Institute for Reactor Materials, KFA-Jülich. Prior to joining KFA in 1976, he was with INCO Europe Ltd. for 11 years and worked on the development of nonferrous nickel-containing alloys. His current interests are the mechanical properties of high-temperature alloys in HTGR environments and the influence of corrosion on mechanical behavior.

PHASE ANALYSIS OF HIGH-TEMPERATURE ALLOYS FOR NUCLEAR APPLICATION BY INTERFERENCE LAYER METALLOGRAPHY

Helmut Hoven
Karl Koizlik
Hubertus Nickel





Helmut Hoven (top) [metallurgical engineer, Nuclear Research Center (KFA) Jülich, 1967] is employed at KFA and is working in the Department for Reactor Materials (IRW), Physical Surface Analysis Section. He is responsible for the working group and laboratories for metallography and ceramography. His main field of interest is interference layer metallography. **Karl Koizlik** (center) (Dr. rer. nat., Technical University of Aachen, 1981) is employed at the KFA and is head of the Physical Surface Analysis Section of IRW. He is working in the field of nuclear materials and development of materials characterization and is responsible for the R&D on materials for the plasma chamber of fusion reactors. **Hubertus Nickel** (bottom) (Dr. rer. nat., Technical University of Aachen, 1959) is head of the IRW at KFA and holds the chair for reactor materials and fuel elements at the Technical University of Aachen. His special field of interest is nuclear materials and safety aspects of nuclear technology. He is a member of the German Reactor Safety Commission.

PRECIPITATION BEHAVIOR OF Ni–Cr–22 Fe–18 Mo (HASTELLOY-X) AND Ni–Cr–22 Co–12 Mo (INCONEL-617) AFTER ISOTHERMAL AGING

Hermann Kirchhöfer
Florian Schubert
Hubertus Nickel

Hermann Kirchhöfer (right) (Dipl.-Ing., material science, University of Erlangen, 1980) has been employed at the Nuclear Research Center at Kernforschungsanlage (KFA) Jülich since 1980. For the past two years he has worked on his thesis, which examines the precipitation behavior of nickel-base alloys. **Florian Schubert** (left) (Dipl.-Physicist, University of Saarland, FRG, 1968; Dr. rer. nat., Technical University of Aachen, FRG, 1974) is head of the materials evaluation office of the Institute for Reactor Materials, KFA-Jülich. He is chairman of the materials working group of the German Research and Development Company of HTR, Entwicklungsgemeinschaft HTR. Before joining KFA he was involved in the R&D of high-temperature superalloys at Thyssen Special Steel Work and Thyssen Investment Casting Work, both in the field of metallurgy and processing. He is currently involved in developing a design code for high temperatures, like multiaxial creep, creep ratcheting, creep buckling, and lifetime prediction. **Hubertus Nickel** (center) [Dr. rer. nat., chemistry and metallurgy, Technical University of Aachen, Federal Republic of Germany (FRG)] has been director of the Department for Reactor Materials in the Nuclear Research Center (KFA), Jülich, FRG. He is also a full professor for reactor materials and nuclear fuel elements at the Technical University of Aachen. In his role as a member of the German Reactor Safety Committee (since 1972), he has been involved with the safety of different reactor types, particularly the standardization of the light water reactor (LWR) as well as the realization of closing the fuel cycle for LWRs.

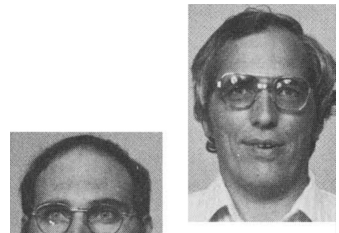
IMPACT STRENGTH AND TRANSMISSION ELECTRON MICROSCOPY INVESTIGATIONS OF AGED AND CARBURIZED ALLOY 800H

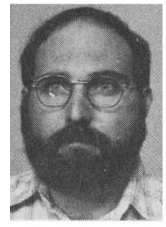
Aleksandra Czyrska-Filemonowicz
Philip J. Ennis

Aleksandra Czyrska-Filemonowicz (top) (Dipl.-Ing., metallurgy, 1969; PhD, physical metallurgy and solid state physics, The Academy of Mining and Metallurgy, Cracow, Poland, 1976) has worked in the Electron Microscopy Group in the physical metallurgy department at the Academy of Mining and Metallurgy since 1975. Her main research activity is in the structure and properties of stainless steels and superalloys (especially nuclear reactor materials). Currently she is working at the Nuclear Research Centre (KFA) Jülich as a guest scientist. **Philip J. Ennis** (BSc, physical metallurgy, University of Birmingham, United Kingdom, 1965) is a research metallurgist at the Institute for Reactor Materials, KFA-Jülich. Prior to joining KFA in 1976, he was with INCO Europe Limited for 11 years and worked on the development of nonferrous nickel-containing alloys. His current interests are the mechanical properties of high-temperature alloys in high-temperature reactor environments and the influence of corrosion on mechanical behavior.

HASTELLOY-X FOR HIGH-TEMPERATURE GAS-COOLED REACTOR APPLICATIONS

H. E. McCoy
J. P. Strizak
J. F. King

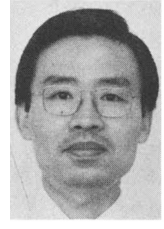




H. E. McCoy (top) (PhD, metallurgical engineering, University of Tennessee, 1964) is studying the effects of various environments on the creep behavior of several materials while he is a research metallurgist at Oak Ridge National Laboratory (ORNL). **J. P. Strizak** (center) (MS, mechanical engineering, Pennsylvania State University, 1974) is a research metallurgist at ORNL and is performing fatigue studies in air and controlled environments on numerous engineering materials. **J. F. King** (bottom) (BS, welding engineering, Ohio State University, 1968) is involved in developing suitable welding techniques for numerous engineering materials in his capacity as a research metallurgist at ORNL.

MECHANICAL PROPERTIES OF HEAT-RESISTANT ALLOYS EXPOSED TO AIR AND HTGR HELIUM AT HIGH TEMPERATURES

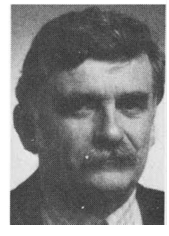
Junzo Fujioka
Norio Fukasako
Hirokazu Murase
Yukio Nishiyama



Junzo Fujioka (top right) (Dr., metallurgical engineering, Kyoto University, 1982) has worked at Kawasaki Heavy Industries, Ltd. (KHI) since 1968 and is assistant manager of the materials research department. His area of interest is the relationship between mechanical properties and microstructural factors of heat-resistant alloys used for high-temperature gas-cooled reactors (HTGRs) and gas turbines. **Norio Fukasako** (top left) (BS, 1967, and MS, 1970, metallurgical engineering, Kumamoto University) is assistant manager of the corrosion research department at KHI. For the past 10 years, he has studied high-temperature corrosion of materials used for HTGRs and boilers. **Hirokazu Murase** (bottom right) (Dr., nuclear engineering, Osaka University, 1962) has worked at KHI since 1959 and is manager of the materials research department. His special interests are corrosion and tribology of materials used for HTGRs and boilers. **Yukio Nishiyama** (bottom left) (Dr., metallurgical engineering, Kyoto University, 1979) has worked at the jet engine division at KHI and has engaged in R&D of materials for gas turbine engines since 1955. He is now head of the materials research department.

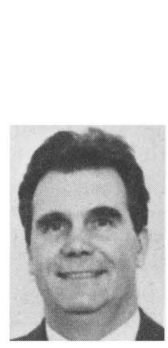
MECHANICAL CHARACTERIZATION OF METALLIC MATERIALS FOR HIGH-TEMPERATURE GAS-COOLED REACTORS IN AIR AND IN HELIUM ENVIRONMENTS

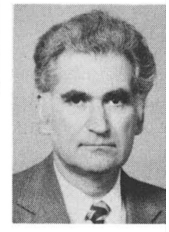
G. Sainfort
J. Sannier
M. Cappelaere
J. Grégoire



G. Sainfort (right) (Engineer Doctor, ENSMA, Poitiers; MS, Poitiers, 1956) is head of the radiometallurgy section in the metallurgy department of the Nuclear Research Center at Grenoble. Areas within his responsibility include the high-temperature behavior of materials for nuclear applications (components

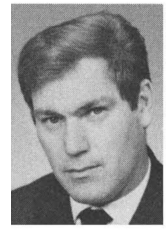
for fast breeder and high-temperature reactors) and more fundamental research on microstructure and the grain boundaries in metals. **J. Sannier** (top) (Chemical Engineer, Ecole Nationale Supérieure de Chimie, Paris), a senior engineer, joined Commissariat à l'Energie Atomique (CEA) in 1956 and works in the corrosion and the fluid chemistry department at the Fontenay-aux-Roses Nuclear Research Center where he is in charge of problems of corrosion by gas and liquid metals. **M. Cappelaere** (center) (Chemical Engineer, Faculté des Sciences, Paris) has been with the corrosion and fluid chemistry department of the Fontenay-aux-Roses Nuclear Research Center since 1960. He is currently in charge of corrosion tests with gas and liquid metals. **J. Grégoire** (bottom) (Electrometallurgical Engineer, Grenoble) joined the CEA in 1962 and is currently with the metallurgy department of the Nuclear Research Center at Grenoble in charge of the high-temperature metal deformation studies.





EVALUATION OF HIGH-TEMPERATURE ALLOYS FOR HELIUM GAS TURBINES

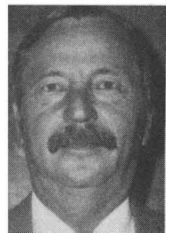
Wolfgang Jakobeit
Jörn-Peter Pfeifer
Georg Ulrich



Wolfgang Jakobeit (top) (Dipl.-Ing., mechanics, Technical University of Braunschweig, 1960) has been employed in the Central Material Laboratory of Brown Boveri & Company, Ltd., Mannheim, since 1961, where he is involved with the high-temperature properties of steels and superalloys (tensile, creep, low-cycle fatigue). Besides those investigations, he is also working on the development of a turbine blade made of Mo-TZM. He is the group leader of the Creep Testing Laboratory. **Jörn-Peter Pfeifer** (center) (Dr. rer. nat., physical chemistry, University of Bonn, 1969) was employed at the German Mass Spectrometer Company in 1963 and at the Max Planck Institute for Radiation Chemistry, Mülheim, in 1965. In 1970 he moved to the University of California, Berkeley, and was concerned with field ion mass spectrometry. He has been working on creep properties and corrosion effects of high-temperature alloys at the Kernforschungsanlage Jülich since 1972. **Georg Ullrich** (bottom) (Dipl.-Ing., metallurgist, University of Clausthal and Saarbruecken, 1961) was a junior scientist in industry from 1961 to 1962. Since 1963 he has worked at the Swiss Federal Institute for Reactor Research. He has been head of the metallurgical department at the institute since 1979.

MECHANICAL PROPERTIES OF WELDS IN COMMERCIAL ALLOYS FOR HIGH-TEMPERATURE GAS-COOLED REACTOR COMPONENTS

James R. Lindgren
Brian E. Thurgood
Robin H. Ryder
Chia-Chuan Li



James R. Lindgren (right) (BS, metallurgical engineering, Michigan Technical University, 1952) is on the research staff for metallurgical engineering at GA Technologies, Inc. (GA). He is involved in testing and fabrication development of structural

metals used in the high-temperature gas-cooled reactor. **Brian E. Thurgood** (top) (MI, mechanical engineering, Lutton College of Technology, 1958) is manager of materials applications at GA. He is involved in welding and metallurgical R&D directed at materials for high-temperature service. **Robin H. Ryder** (center) (MS, mechanical engineering, Cronfield College of Technology, 1960) is manager of experimental structural mechanics at GA. He specializes in experimental and theoretical structural mechanics applied to components that need to operate at elevated temperatures. **Chia-Chuan Li** (bottom) (PhD, metallurgical engineering, University of Michigan, 1977) is a senior engineer at GA, where he specializes in high-temperature mechanical properties of heat-resistant alloys and ferritic steels, welding, friction and wear, and coating of materials.