International Aerospace Literature

During 1997 the *AIAA Journal* will carry selected aerospace literature abstracts on leading research topics from Russia, Japan, France, Germany, Italy, and the United Kingdom. The topics will be chosen and the abstracts reviewed for pertinency by *AIAA Journal* editors. This month features Materials Microstructures from Russia, Japan, Germany, and the United Kingdom.

Support for assembling and publishing the selected abstracts has been provided by the Innovative Science and Technology Directorate of the Strategic Defense Initiative Organization (SDIO), with the sponsorship and technical management of the abstract service by the Office of Naval Research (ONR) under ONR Grant N00014-93-I-1074.

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Russian Aerospace Literature
This month: *Materials Microstructures*

A96-44874 The influence of double-ageing on the short-transverse elongation of Al-Li-Cu-Zr rolled plate. V. N. ANANIEV (All-Russia Inst. of Light Alloys, Moscow, Russia), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 865–870. 5 Refs. Documents available from AIAA Dispatch.

GB T1 precipitates were found to have a significant influence on the elongation of rolled 1450 plate (Al-2.1Li-2.8Cu-0.1Zr) in the S-T direction. The double-aging treatment with a prolonged first low temperature stage was proposed. The intensification of solid solution decomposition in matrix on double-aging decreases the size of GB precipitates and increases the S-T elongation at the same strength level. (Author)

A96-42627 Influence of porosity on transverse rupture strength and fracture toughness of two-phase alloy. A. V. LAPTEV (Ukrainian National Academy of Sciences, Inst. for Problems of Materials Science, Kiev, Ukraine), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 313–320. 18 Refs. Documents available from AIAA Dispatch.

A study of structure, transverse rupture strength, and fracture toughness of WC-16 wt% Co hard metal, depending on relative porosity yawing over a range of 0–25%, was carried out. The specimens were produced by hot pressing under a pressure of around 500 MPa and also by sintering (without pressure). Porosity variation was performed by means of changes of powder mixture consolidation temperature over the 950–1400°C range. It is ascertained that in hot-pressed specimens, transverse rupture strength and fracture toughness depend on porosity as a linear function. A linear pattern of porosity variation with relatively high rate is caused by the effect of not only porosity, but also other structural parameters. With this, an interface quality (strength) is of most importance. The ambiguous effect of porosity in specimens produced in different ways is an indirect corroboration of the multifactor effect on the mechanical properties of porous specimens. (Author)

A96-42619 Influence of shock-wave ultrafine particles on some properties of hardmetals composites. Y. GORDEEV, V. REDKIN, and A. STAVER (Krasnoyarsk State Technical Univ., Russia), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 135–140. 2 Refs. Documents available from AIAA Dispatch.

Using experimental methods, the possibilities of improving the quality of hard metals by introducing ultrafine particles were determined. Some physical and mechanical properties of hard-metal composites strengthened by ultrafine additives are presented. Geometric models for such composites are suggested. The present model is an attempt at predicting the relationship between fracture toughness and such microstructural parameters as average size and volume fraction of ultrafine particles introduced in the binder layer between the carbide grains. (Author)

A96-42405 Thermal stability of submicrocrystalline copper and Cu:ZrO_2 composite. A. B. LEBEDEV, S. A. PULNEV, Y. A. BURENKOV, V. V. VETROV (Russian Academy of Sciences, Physical-Technical Inst., St. Petersburg, Russia), V. I. KOPYLOV (Belarus Academy of Sciences, Physical-Technical Inst., Minsk), and O. V. VYLEGZHANIN (St. Petersburg State Technical Univ., Russia), *Scripta Materialia* (ISSN 0022-4928), Vol. 35, No. 9, 1996, pp. 1077–1081. 19 Refs. Documents available from AIAA Dispatch.

The effect of annealing on the yield stress and Young's modulus in heavily deformed Cu and precipitate-hardened Cu:ZrO_2 composite with ultrafine-grained structure is reported. Good thermal stability of the yield stress for heavily deformed Cu:ZrO_2 within a temperature range of 20–500°C is demonstrated.

A96-42179 Effective properties of piezoactive matrix composites (Ob ehffektivnykh svojstvakh p'ezoaktivnykh matrichnykh kompozitnykh materialov). V. M. LEVIN, *Prikladnaya Matematika i Mekhanika* (ISSN 0032-8235), Vol. 60, No. 2, pp. 313–322. In Russian. 9 Refs. Documents available from AIAA Dispatch.

Reinforced matrix composites are considered assuming that both the matrix and the reinforcement are perfectly elastic and have piezoelectric properties. The method of the effective field is used to determine the effective electrical and elastic characteristics of such composites with allowance for the electroelastic coupling effects. Explicit expressions are obtained for the electroelastic characteristics of composites reinforced by spherical inclusions and continuous cylindrical fibers.

A96-42143 A systems analysis of dispersion-strengthened alloys (Sistemnyj analiz dispersno-uprochnennykh splavov). V. I. PSAREV, L. A. PARKHOMENKO, and A. F. KULIKOV, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 142–150. In Russian. 16 Refs. Documents available from AIAA Dispatch.

A method is proposed for establishing a possible correlation between changes in the experimental histograms with the microparticle growth time in an alloy and processes within the system that are responsible for the transformation of distributions. Expressions are obtained which can be used to assess the validity of the results of a systems analysis. This provides a way to better identify theoretical and experimental microparticle size distributions in dispersion-strengthened alloys. Histograms of Al_3Mg_2 disperse particles in an aluminum-magnesium alloy under isothermal heating at 430°C for 5 h are examined as an example.

A96-42142 A study of temperature-induced stress relaxation in aluminum alloy 1420 (Issledovanie protsessa temperaturnoj relaksatsii napryazhenij v alyuminievom splave 1420). I. M. MAMONOV, M. Y. KOLLEROV, and M. V. KUNYAVSKIJ, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 131–135. In Russian. 5 Refs. Documents available from AIAA Dispatch.

Macrostress relaxation curves for Al-Li alloy 1420 are presented. The relaxation parameters are determined as a function of temperature. The effect of the initial structure of the alloy on the relative relaxation rate and the relaxation compliance index is investigated. Mathematical expressions are obtained which provide a way to calculate stress relaxation in alloys of different initial structures at various temperatures.

A96-42140 Nickel self-diffusion along internal interfaces in a high-temperature alloy based on a complex-alloyed Ni_3Al intermetallic (Samodiffuziya nikelya po vnutrennim poverkhnostyam razdela v zharoprochnom splave na osnove slozhnolegirovannogo intermetallida Ni_3Al). E. Y. ARISTOVA, E. N. BELOVA, Y. A. BONDARENKO, V. P. BUNTUSHKIN, S. S. GINZBURG, E. N. KABLOV, V. G. NEFEDOV, and I. M. RAZUMOVSKIJ, *Metally* (ISSN 0869-5733), No. 3,1996, pp. 113–120. In Russian. 12 Refs. Documents available from AIAA Dispatch.

Nickel self-diffusion along internal interfaces in single-crystal ingots of complex Ni_3Al-base alloys is investigated experimentally using layer-by-layer radiometric analysis and high-resolution autoradiography. The diffusion permeabilities of the surfaces are measured in the temperature range 700–900°C, and the

activation energies are calculated. It is found that accelerated diffusion occurs mainly in primary precipitates at the boundaries of dendritic cells. The effect of solidification gradients on the diffusion parameters is examined.

A96-42139 Phase stability of single crystals of high-temperature Ni-Al-Cr-W-Ta-Mo nickel alloys (Fazovaya stabil'nost' monokristallov zharoprochnykh nikelevykh splavov Ni-Al-Cr-W-Ta-Mo). N. V. PETRUSHIN, E. B. CHABINA, and L. A. D'YACHKOVA, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 104–112. In Russian. 13 Refs. Documents available from AIAA Dispatch.

Results of a study of the microstructure and temperature of phase transformations in cast single crystals of high-temperature Ni-Al-Cr-W-Ta-Mo alloys are reported. The concentration dependence of the volume fraction of the alpha phase and the position of the phase boundary (gamma + gamma prime)/(gamma + gamma prime + alpha) in this system are estimated analytically. The results provide a way to predict the formation of alpha-phase precipitates in the actual production of single crystals of high-temperature alloys by directional solidification.

A96-42138 Structure and properties of chromium-rich alloys in the Cr-Ti-Si system (Struktura i svojstva splavov khromovogo ugla sistemy Cr-Ti-Si). K. B. POVAROVA, E. K. ZAVARZINA, S. I. YUDKOVSKIJ, A. G. FRIDMAN, and V. G. IVANCHENKO, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 95–103. In Russian. 11 Refs. Documents available from AIAA Dispatch.

A group of chromium-rich two-phase (Cr) + lambda alloys has been identified in the Cr-Ti-Si system. These alloys have a composition that is close to the solubility limit of Cr_3Si in (Cr) + lambda. The structure of these alloys is characterized by high stability at high temperatures, which results in a low softening rate with increasing temperature up to 1200°C, high hot hardness, and high creep resistance at 1153°C, combined with satisfactory room-temperature fracture toughness. Such alloys are attractive materials for structural and toolmaking applications.

A96-42137 Phase composition and structure of NiAl-base alloys of the system Ni-Al-Co-M, where M is Ti, Zr, Hf, V, Nb, Ta, Cr, or Mo (Fazovyj sostav i struktura splavov na osnove NiAl sistem Ni-Al-Co-M, gde M-Ti, Zr, Hf, V, Nb, Ta, Cr, Mo). K. B. POVAROVA, N. K. KAZANSKAYA, B. S. LOMBERG, D. Y. SHKOL'NIKOV, S. A. FILIN, and M. D. BESPALOVA, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 85–94. In Russian. 3 Refs. Documents available from AIAA Dispatch.

A study is made of the effect of IV-VI transition metals (0.27–23 at.%) on the structure and phase composition of beta-gamma Ni-Al-Co alloys. The results of the study indicate that high-temperature nickel alloys with a density of 7.3 g/cu cm or less can be based on beta-gamma two-phase alloys with possible secondary precipitation of the gamma-prime phase during heat treatment. The content of Mo, Ta, Nb, and V must not exceed 1–1.8 at.% while the contents of Ti and Cr may be as high as 3 and 12 at.%, respectively.

A96-42136 Structural state of heat treated iron-nickel alloys at low temperatures (Strukturnoe sostoyanie zakalennykh zhelezonikelevykh splavov pri nizkikh temperaturakh). O. A. BANNYKH and V. E. DANIL'CHENKO, *Metally* (ISSN 0869-5733), No. 3, 1996, pp. 77–84. In Russian. 19 Refs. Documents available from AIAA Dispatch.

Changes in the crystal structure of newly formed martensite in single crystals of Fe-Ni alloys during heating in the cryogenic temperature range are investigated experimentally using X-ray diffraction analysis. The study reveals a large variety of structural changes in the newly formed martensite, which is attributed to the superposition of two processes: 1) coherent stress relaxation and 2) redistribution of carbon atoms within the crystal lattice.

A96-41973 Effect of microstructure on erosive combustion of energetic materials. Y. I. DIMITRIENKO (NPO Mashinostroeniya, Reutov, Russia), *Energetic materials—Technology, manufacturing and processing; Proceedings of the 27th International Annual Conference of ICT*, Karlsruhe, Germany, 1996 (A96-41945 11-28), Pfinztal, Germany, Fraunhofer-Institut fuer Chemische Technologie, 1996, pp. 63-1–63-14. 4 Refs. Documents available from AIAA Dispatch.

A new model of erosive combustion of energetic materials is developed, that, unlike classical models reducing erosive combustion only to turbulence, takes account also of the phenomenon of mechanical erosion (dispersing) of a combustion surface in a high-speed hot flow. Conducted theoretical investigations determine the effect of microstructural parameters (for example, of a content of inert fillers) on a rate of erosive combustion of energetic materials. Experimental investigations of erosive combustion are also conducted that verify a validity of the suggested model. (Author)

A96-41678 Thermohydrogen treatment—The base of hydrogen technology of titanium alloys. A. A. ILYIN, A. M. MAMONOV, V. K. NOSOV (Moscow State Univ. of Aviation Technology, Russia), and I. S. POLKIN (All-Russia Inst. of Light Alloys, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2462–2469. 6 Refs. Documents available from AIAA Dispatch.

The scientific principles of the thermohydrogen treatment (THT) of titanium alloys are presented. The basic technological processes are based on controlling the mechanism and kinetics of the phase transformation in hydrogen-alloyed materials. The effect of THT on the structural and mechanical properties of as-cast powder metallurgy and deformed semiproducts of different titanium alloys is discussed. The most promising application fields of the THT of titanium alloys are considered. (Author)

A96-41673 Demands to bimodal structure with optimal combination of mechanical properties and regimes for its development. M. BRUN and G. SHACHANOVA (All-Russia Inst. of Light Alloys, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2421–2429. 12 Refs. Documents available from AIAA Dispatch.

Problems concerning a bimodal structure in alpha + beta titanium alloys are discussed. The parameters of this structure providing an optimal combination of properties are considered. The significance of initial structure preparation for ensuring a bimodal structure is analyzed. (Author)

A96-41638 High power microwave treatment of titanium alloy details. V. A. SHULOV (Moscow Aviation Inst., Russia), N. A. NOCHOVNAYA, T. M. ORESHNIKOVA (All-Russia Inst. of Aviation Materials, Moscow, Russia), A. N. DIDENKO (Russian Academy of Sciences, Dept. of Physical and Technical Problems of Energetics, Moscow, Russia), A. S. SULAKSHIN, and A. M. ZHERLITCEN (Inst. of Nuclear Physics, Tomsk, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2119–2125. 6 Refs. Documents available from AIAA Dispatch.

Investigations of the influence of high-power microwaves on the physical and chemical states of surface layers and the service properties of titanium refractory alloy parts were carried out. It was shown that high-power microwave irradiation allows an increase of the fatigue strength and heat gas corrosion resistance of titanium alloy details even at low values of the pulse power density. The perspectives and advantages of the application of high-power microwave treatment in aircraft material science are discussed. (Author)

A96-41636 Gaseous stabilized interstitial inclusions in titanium ingots and products. V. V. TETYUKHIN, V. V. SAVELYEV (Verkhnaya Salda Metallurgical Production Association, Russia), V. M. MUSATOV, A. D. CHUCHURYUKIN (All-Russia Inst. of Light Alloys, Moscow, Russia), V. M. ILYENKO, and B. I. BUTSEV (All-Russia Inst. of Aviation Materials, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2104–2110. Documents available from AIAA Dispatch.

Of all the different defect types which have to be detected in titanium parts by destructive methods of inspection the most difficult ones to detect are gaseous stabilized interstitial inclusions. Their detection by means of widely used NDT testing methods is achieved with great difficulty. The cause of interstitial gaseous stabilized inclusion formation could be either the introduction of high-percentage gas impurities or the emergence of cracks, forging laps, shrinkage cavities, etc. during intermediate deformation stages, where cavities extend to the outer surface. Simulation of both processes has been performed. Simulation of the formation of gaseous stabilized interstitial inclusions in the ingot is achieved by introduction of nitrided titanium sponge into the consumable cast electrode. The nitrogen content in the above sponge was 4, 12, and 16 wt%. Nitrided titanium sponge was introduced via a hole drilled in each electrode. The melted ingots were forged into bars, and ultrasonic inspection successfully detected the defects. The results demonstrate that the nitrided sponge formed the gaseous stabilized inclusion in the ingots at all nitrogen levels.

A96-41629 Ion implantation into titanium alloys for application in aircraft building. V. A. SHULOV (Moscow Aviation Inst., Russia), N. A. NOCHOVNAYA, and T. M. ORESHNIKOVA (All-Russia Inst. of Aviation Materials, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2039–2045. 11 Refs. Documents available from AIAA Dispatch.

The choice of the types of ions and irradiation processes for the ion implantation process in high-temperature refractory titanium alloys was investigated. The effects of ion implantation and final heat treatment process on the physical and chemical state of the layers of titanium alloy compressor blades were studied. It was established that the chemical composition changes and structure transitions proceed in the surface layers of titanium alloy parts to a depth of 1 μ due to implantation of N+, B+, C+, La+, and Pd+ at low energies and ion current densities. To increase the modified surface layer thickness up to h(M) = 5–6 μ, the ion implantation process has to be carried out at higher values of ion current densities with irradiating targets being water-cooled. Ion implantation allows improvements in the main service properties of titanium alloy parts, namely: fatigue strength by 5–20%, heat gas corrosion resistance by two times or more, sand particle erosion resistance by 20–50%, and salt gas corrosion resistance by three times or more. The treatment of titanium alloy aircraft compressor blades using ion-beam technologies was developed on the basis of the experimental results. (Author)

A96-41542 Hydrogen effect on mechanical properties of Ti-6Al-4V ELI alloy at low and cryogenic temperatures. B. A. KOLACHEV, N. N. KONDRASCHEVA, and P. D. DROZDOV (Moscow State Univ. of Aviation Technology, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1034–1041. 11 Refs. Documents available from AIAA Dispatch.

The paper deals with the effect of hydrogen on the mechanical properties of Ti-6Al-4V alloy at low and cryogenic temperatures up to the boiling point of

liquid helium. It is shown that Ti-6Al-4V alloy was the most subject to hydrogen-induced delayed failure in the temperature range from 253 to 293 K. Not one case of full brittle fracture was observed in tests on tensile properties and impact ductility at hydrogen contents from 0.003 to 0.1 wt% within the temperature range from room temperature up to 4 K. Hydrogen embrittlement of Ti-6Al-4V alloy did not develop within the temperature interval from 293 to 4 K for hydrogen content within the limits of standard specifications (below 0.01% wt.) for Ti-6Al-4V ELI alloy during tensile and impact ductility tests. (Author)

A96-41518 Manufacture of billets and bars with regulated structure and mechanical properties for aircraft engines disks and blades forgings and other critical parts. I. LEVIN, A. SHIBANOV, V. TETYUKHIN (VSPMO, Russia), and V. ARZHAKOV (VIAM, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 774–777. Documents available from AIAA Dispatch.

A process for the manufacture of billets and bars of titanium alloys for aircraft engine fan disks and blades is described. The process includes hot deformation to produce a regulated beta grain size and subsequent deformation of the billet in the alpha + beta field to obtain an equiaxed alpha microstructure. Deformation of the ingots is carried out at 150–200°C above the beta transus temperature in order to obtain higher ductility and enhanced workability of the metal. A regulated beta grain size is produced through a combination of heating and deformation stages at temperatures above and below beta transus. To intensify the process of alpha spheroidization, the billet is rapidly quenched after beta deformation or additionally heated in the range of beta transus. Final deformation of the billet is carried out in the alpha + beta field to a minimum of 75–80% for forgings and 60–70% for subsequent bar rolling. The mechanical properties of 250-kg disk forgings and blade forgings with a projection area of 2400 sq cm of Ti-6Al-4V alloy are presented.

A96-41517 Manufacture of disc and blade forgings from VT22 alloy for aircraft engine fans. U. I. ZAKHAROV (VIAM, Moscow, Russia), V. V. TETYUKHIN (VSPMO, Russia), V. M. ARZHAKOV (VIAM, Moscow, Russia), I. V. LEVIN, and A. S. SHIBANOV (VSPMO, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 770–773. Documents available from AIAA Dispatch.

The high strength (1078–1176 MPA) and good ductility characteristics of large forgings of VT22 titanium alloy allow the use of this alloy for the manufacture of high-strength fan disks and fan blades for aircraft engines. The use of this alloy makes it possible to reduce the fan mass and increase compression. The forging of 320 mm diam billets for the manufacture of fan disks is carried out in saddle dies on hydraulic presses with a rated capacity of 30 and 60 MN. Final forging is carried out at a temperature 30°C below the beta transus, with a total deformation of 66–80%, which allows a sufficient amount of work along the entire length of the billet. Large disk forging may have a mass of 250 kg and a maximum cross section of 120 mm; the disks are forged in hydraulic presses with a force of 300 MN. Blade forging are made using billets of 130–160 mm diam, which are then shaped and die-forged at 30°C below beta transus. The microstructures and properties of the disks and blades are presented.

A96-40943 Peculiarities of Ti dendritic segregation in aluminium alloys. O. A. SETIUKOV and I. N. FRIDLYANDER (All-Russia Inst. of Aviation Materials, Moscow, Russia), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 1, 1996, pp. 195–200. 2 Refs. Documents available from AIAA Dispatch.

Titanium concentration throughout the dendrite cells section of Al solid solution in as-cast and as-annealed at high temperatures conditions of binary, ternary and commercial Al alloys has been defined using the method of X-ray electron probe analysis. Ti content in alloys was varied from 0.03 to 0.3%. Ti concentration in the central zones of Al dendrite cells may exceed its average content in the melt by 6–8 times, whereas it is practically equal to zero at the periphery. Variation of Zn, Mg and Cu content within the limits of their solubility in Al, Mn and Cr additions, and Fe and Si impurities, have no significant effect on Ti intercrystalline segregation in Al. The stability of supersaturated Al solid solution in Ti enriched regions depend on alloying elements and heat treatment conditions. Linear dependence is observed between Ti average content in the melt and its maximum concentration in Al solid solution. It is shown that a limiting equilibrium solubility of Ti in Al solid solution is no less than 1.3%. (Author)

A96-40316 Formation of omega-phase in Zr-4 at.% Cr alloy. A. V. DOBROMYSLOV and N. V. KAZANTSEVA (Russian Academy of Sciences, Inst. of Metal Physics, Yekaterinburg, Russia), *Scripta Materialia* (ISSN 1359-6462), Vol. 35, No. 7, 1996, pp. 811–815. 11 Refs. Documents available from AIAA Dispatch.

The formation of the omega phase in a Zr-4 at.% Cr alloy was investigated experimentally using X-ray diffraction analysis and optical and transmission electron microscopy. The results of the study suggest that, in alloys quenched from 1100°C, two competitive processes take place, the beta-omega transformation and the beta-alpha prime transformation. Well developed martensitic structure is observed only in some areas of the alloy, indicating that the formation of the omega phase begins near the martensitic transformation temperature. In the as-quenched alloy, the omega phase is observed in regions consisting of extremely small particles with a very high density. The appearance of these regions, that look like pearlite, testifies that the metastable eutectoid decomposition occurs in this alloy.

A96-39620 Development of Nd-Fe-B alloys with enhanced temperature stability of the structure and magnetic properties (Razrabotka splavov na osnove Nd-Fe-B s povyshennoj temperaturnoj stabil'nost'yu struktury i magnitnykh svojstv). A. A. ALBUTOV, A. S. LILEEV, V. P. MENUSHENKOV, P. S. SHMAKOV, and A. M. GABAJ, *Metally* (ISSN 0869-5733), No. 2, 1996, pp. 79–85. In Russian. 15 Refs. Documents available from AIAA Dispatch.

Results of a study of permanent magnets made of Nd-Fe-B-based systems alloyed by Dy, Tb, Co, Nd, and Ga are reported. The effect of Nb and Ga on the magnetic properties and microstructure of the sintered magnets is investigated. It is found, in particular, that the addition of Nb and Ga increases the coercive force of magnetization to 2000 kA/m while also improving the temperature stability of the magnets. The working temperature increases to 150°C and, for short-period operation, to 180–200°C.

A96-39617 Effect of the reversible alpha-alpha + sigma transformation on the structure of Fe-Cr-Co-Mo alloys (O vliyanii/alpha-reversible-alpha + sigma/-prevrashcheniya na strukturu splavov Fe-Cr-Co-Mo). V. S. SHUBAKOV, N. V. MENUSHENKOVA, A. V. KONDRASHENKO, and B. A. SAMARIN, *Metally*, (ISSN 0869-5733), No. 2, pp. 42–45. In Russian. 3 Refs. Documents available from AIAA Dispatch.

A study is made of the region of the alpha-alpha + sigma transformation in a Fe-30% Cr-15% Co-3% Mo alloy and of the effect of the amount of the sigma phase on the structure of the single-phase alpha state. It is found, in particular, that the dissolution of the sigma phase in the alloy leads to a redistribution of defects, resulting in a rapid formation of a substructure and high-angle recrystallization centers. The dependence of the size of the recrystallized grain of the alpha solid solution on the amount of the sigma phase is similar to the grain size dependence after recrystallization on the extent of cold plastic deformation of the single-phase alloy.

A96-38411 Isomorphic concentration transitions in Ni_3Mn-Ni_3Al and Ni_3Mn-Ni_3Si systems (Izomorfnye kontsentratsionnye perekhody v sistemakh Ni_3Mn-Ni_3Al i Ni_3Mn-Ni_3Si). V. I. GOMAN'KOV, S. M. TRET'YAKOVA, I. V. ISAKOV, and V. A. CHEVYCHELOV, *Rossijakaya Akademiya Nauk, Metally* (ISSN 0869-5733), No. 1, 1996, pp. 160–164. In Russian. 10 Refs. Documents available from AIAA Dispatch.

The structural states of Ni_3Mn-Ni_3Al and Ni_3Mn-Ni_3Si alloys are determined calorimetrically and by neutron and X-ray diffraction analyses. Measurements of the Kurnakov temperature as well as long-term order and lattice parameters are presented along with a phase diagram of the ordered alloys. It is found that concentration transitions in the alloys are isomorphic. The substitution sites in the fcc lattices in the case of alloying by a third element are determined.

A96-38410 A study of the heat resistance of an Nb-Ti-Al alloy based on intermetallics (Issledovanie zharostojkosti splava na osnove intermetallidov sistemy Nb-Ti-Al). O. A. BANNYKH, E. N. SHEFTEL', G. SH. YSMANOVA, A. A. SHARAPOV, O. A. FILIP'EVA, and A. E. TEREKHIN, *Rossijakaya Akademiya Nauk, Metally* (ISSN 0869-5733), No. 1, 1996, pp. 60–66. In Russian. 10 Refs. Documents available from AIAA Dispatch.

The structure, phase composition, and oxidation kinetics of an intermetallic alloy containing 47% Nb, 23.9% Ti, 21% Al, 4.4% V, and 4.1% Cr (by mass) were investigated in the temperature range 800–1400°C. The alloy has a two-phase (sigma + gamma) structure. High-temperature treatment in air at 1400°C for 1–3 h is shown to reduce the subsequent oxidation rate at 1150°C by a factor of 2-3.

A96-35569 The formation of alpha double prime phase in Zr-Re alloys. A. V. DOBROMYSLOV and N. I. TALUTS (Russian Academy of Sciences, Inst. of Metal Physics, Yekaterinburg, Russia), *Scripta Materialia* (ISSN 1359-6462), Vol. 35, No. 5, 1996, pp. 573–577. 7 Refs. Documents available from AIAA Dispatch.

The microstructure of quenched Zr-Re alloys containing 0.5, 1.5, and 2 at.% Re was investigated by X-ray diffraction analysis and optical and electron microscopy with a view to identifying the orthorhombic alpha double prime phase. It is found that, in the Zr-1.5 at.% Re alloy, the orthorhombic alpha double prime phase is formed instead of the hexagonal alpha prime phase formed in the Zr-1 at.% Re alloy. The formation of the alpha double prime phase is completely suppressed in the Zr-2 at.% Re alloy.

A96-30583 Grain boundaries structure and mechanical properties of aluminium alloys. N. K. TSENEV (Ufa State Petroleum Technological Univ., Russia), *Materials Science Forum* (ISSN 0255-5476), Vols. 207–209, Pt. 2, 1996, pp. 841–844. 6 Refs. Documents available from AIAA Dispatch.

We discuss the problem of the influence of grain boundary structure on the mechanical properties of aluminium alloys at elevated temperatures. The data indicate grain boundaries that are unique, as well as random grain boundaries. The fitting of calculation results on the contributions of different mechanisms of deformation to the total deformation of alloys with different types of grain boundaries is also given. (Author)

A96-30582 Evolution of intergranular boundary structure during severe plastic deformation in aluminium alloys with different initial grain sizes. N. K. TSENEV, I. R. KIZEEV (Ufa State Petroleum Technological Univ., Russia), and B. E. SELSKY (Bashkirian Scientific Research and Design Inst. of Petroleum Machine Building, Ufa, Russia), *Materials Science Forum* (ISSN 0255-5476), Vols. 207–209, Pt. 2, 1996, pp. 837–840. 4 Refs. Documents available from AIAA Dispatch.

We discuss the regularities of submicron-grained (SMG) structure formation: a structure with grain size of about 0.1 μ in a number of model and commercial aluminum alloys. The SMG structure was produced in the alloys by means of a strain-heat treatment, which includes ultimately large plastic deformation and

fixing the initial stages of recrystallization. The alloy mechanical properties were studied at room and elevated temperatures. (Author)

A96-30549 The formation of grain boundaries during plastic deformation of LiF single crystals. R. KAIBYSHEV and O. SITDIKOV (Russian Academy of Sciences, Inst. of Metals Superplasticity Problems, Ufa, Russia), *Materials Science Forum* (ISSN 0255-5476), Vols. 207–209, Pt. 2, 1996, pp. 485–488. 8 Refs. Documents available from AIAA Dispatch.

The microstructural evolution of 100-plane-oriented LiF single crystals has been studied during plastic deformation at T = 1073 K. It has been shown that plastic deformation leads to formation of low-angle grain boundaries and their transformation to high-angle ones. Further plastic deformation leads to intensive grain boundary migration after some critical strain. The type of structural changes occurring in LiF single crystals is determined by the character of the crystallographic slip. The reasons for critical strain existence, and for the transition from 'rotation' dynamic recrystallization to one of 'migration', are discussed. (Author)

A96-30406 Orientation properties of grain boundaries in one- and two-dimensional aluminum polycrystals (Orientatsionnye svojstva granits zeren v odno- i dvumernykh polikristallakh alyuminiya). V. G. SURSAEVA, T. V. TATSIJ, and L. S. SHVINDLERMAN (RAN, Inst. Fiziki Tverdogo Tela, Chernogolovka, Russia), *Rossijskaya Akademiya Nauk, Izvestiya, Seriya Fizicheskaya* (ISSN 0367-6765), Vol. 60, No. 2, 1996, pp. 180–191. In Russian. 13 Refs. Documents available from AIAA Dispatch.

Data are obtained on grain orientation and misorientation in bamboo-structure wire and in columnar foil. The orientations of individual grains are determined by using electron channeling images obtained in a scanning electron microscope using the selected area method. The statistical grain orientation and misorientation distributions are presented in graphic form.

A96-26383 Diffraction gratings formation on porous silicon using CO_2 laser. A. DAR'JUSHKIN, V. KARAVANSKII, S. KOROVIN, V. PUSTOVOY, and K. TIMOSHECHKIN (Russian Academy of Sciences, Inst. of General Physics, Moscow, Russia), *Proceedings of the ALT '95—International Symposium on Advanced Materials for Optics and Optoelectronics*, Prague, Czech Republic, 1995 (A96-26376 06-74), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 2777), 1996, pp. 53–58. 3 Refs. Documents available from AIAA Dispatch.

A study is made of the periodic structure of a porous silicon layer exposed to two interfering coherent beams of CO_2 laser radiation. By using an electron microscope, the grating period is found to be about 10 μ. The temperature and pressure of porous silicon are evaluated on the basis of the existing models of optoacoustic action. Measurements of the Raman spectra of the periodic structure also indicate that high-power CO_2 laser radiation induces changes in the sample microstructure.

A96-21552 Effect of annealing on microstructure, phase composition and failure of Al_2O_3-ZrO_2 ceramics at room temperature. N. ORLOVSKAYA, G. KRIVOSHEJ, O. BABIJ (Ukrainian National Academy of Sciences, Inst. for Problems of Materials Science, Kiev, Ukraine), and D. OSTROVOJ (Ukrainian National Academy of Sciences, Inst. for Problems of Strength, Kiev, Ukraine), *Journal of Materials Science Letters* (ISSN 0261-8028), Vol. 15, No. 2, 1996, pp. 166–169. 19 Refs. Documents available from AIAA Dispatch.

We investigate the effect of annealing on the strength and fracture toughness of hot-pressed alumina-zirconia ceramics, noting discrepancies in the data published to date. It is found that the structural and phase transformations in the volume and at the surface of the specimens during annealing exert great influence on the physico-mechanical properties of these ceramics.

A96-20920 Superplasticity and hot rolling of two-phase intermetallic alloy based on TiAl. R. IMAYEV, M. SHAGIEV, G. SALISHCHEV, V. IMAYEV, and V. VALITOV (Russian Academy of Sciences, Inst. for Metals Superplasticity Problems, Ufa, Russia), *Scripta Materialia* (ISSN 1359-6462), Vol. 34, No. 6, 1996, pp. 985–991. 14 Refs. Documents available from AIAA Dispatch.

An examination is conducted of superplastic behavior of a TiAl + Ti_3Al, Ti-46 at.% Al intermetallic alloy with micronic and submicronic grain sizes. These results are applied to the hot rolling process. Increasing quantities of alpha-2 Ti_3Al is found to promote microstructural stabilization through prevention of twins-formation during heating, as well as by retarding grain growth during superplastic deformation.

Japanese Aerospace Literature
This month: *Materials Microstructures*

A96-45186 Transmission electron microscopy of low pressure plasma sprayed CoNiCrAlY coating. K. NOGUCHI, M. NISHIDA, and A. CHIBA (Kumamoto Univ., Kurokami, Japan), *Scripta Materialia* (ISSN 1359-6462), Vol. 35, No. 11, 1996, pp. 1359–1364. 11 Refs. Documents available from AIAA Dispatch.

Preliminary results of investigations of the microstructures of low pressure plasma sprayed CoNiCrAlY coatings are presented, with emphasis on the difference between the microstructure of raw powder material and that of the coating and on the formation mechanism of a wavy laminated structure. The raw powder materials is found to consist of gamma and beta phases, whereas the coating consists mainly of the gamma phase, with the decomposition of fine gamma prime particles observed in the gamma phase matrix. The wavy laminated structure in the coating consists of alternating fine and coarse grain regions.

A96-44913 Precipitation behaviors of beta-phase and changes in mechanical properties of Al-Mg system alloys. Y. NAKAYAMA, T. TAKAAI, and D. JIN (Yamanashi Univ., Kofu, Japan), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 1269–1274. 3 Refs. Documents available from AIAA Dispatch.

It is well known that aluminum-magnesium system alloys are used worldwide as, for example, structural materials for ships, trains, and various containers for cryogenic temperature applications. Al-Mg system alloys, however, have certain important weak points, such as undesirable changes or deteriorations in mechanical properties during extended use. The main objective of the present study is to investigate in detail the relationships between the precipitation process of beta-phase and mechanical properties. (Author)

A96-44898 Improvement of mechanical properties by RRA treatment in Al-SiC(w) composite. T. KOBAYASHI (Toyohashi Univ. of Technology, Japan) and H. TODA (Toyohashi Univ. of Technology; Suzuki Motor Corp., Hamamatsu, Japan), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 1127–1132. 7 Refs. Documents available from AIAA Dispatch.

This paper elucidates the formation of PFZ layers around reinforcements and simultaneous precipitation of the equilibrium phase on the interface. The segregation of the solute atoms in the vicinity of the reinforcements is analyzed. Effects of the PFZ layer and the solute atom segregation in the vicinity of the reinforcement in the discontinuously-reinforced MMC on deformation behavior and strength are analyzed by means of the nonlinear FEM. With a view to eliminating baneful effects exerted by the formation of the PFZ layer which are predicted by the FEM analysis, a new heat treatment procedure developed to control the matrix microstructure by a simple heat treatment process is introduced. Improvement of the mechanical properties in this microstructurally-controlled MMC is also reported. (Author)

A96-44868 Precipitation behaviour of Al-Mg-Si ternary alloys. M. TAKEDA, F. OHKUBO, T. SHIRAI (Yokohama National Univ., Japan), and K. FUKUI (Showa Aluminium Co., Oyama Factory, Japan), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 815–820. 10 Refs. Documents available from AIAA Dispatch.

The strenghening of Al-Mg-Si alloys is based on the precipitation-hardening. To understand the relationship between mechanical properties and heat-treated alloys, the thermal stabilities and the microstructures of the phases which appear as metastable or stable phases in the aging process must be investigated systematically. The combination of differential scanning calorimetry (DSC) and TEM is useful for this purpose. The present investigation is carried out to clarify the relationship between the thermal stabilities of the phases and the precipitation formation by systematic DSC measurements combined with TEM and the Vickers hardness test. (Author)

A96-44561 Fabrication of submicrometer-grained Zn-22% Al by torsion straining. M. FURUKAWA (Fukuoka Univ. of Education, Japan); Z. HORITA, M. NEMOTO (Kyushu Univ., Fukuoka, Japan), R. Z. VALIEV (Ufa State Aviation Technical Univ., Russia), and T. G. LANGDON (Southern California, Univ., Los Angeles, CA), *Journal of Materials Research* (ISSN 0884-2914), Vol. 11, No. 9, 1996, pp. 2128–2130. 15 Refs. Documents available from AIAA Dispatch.

The Zn-22% Al eutectoid alloy is capable of exhibiting very high superplastic elongations, in excess of 2000 percent in tension, when the grain size is in the range of 1–10 μ. This paper describes the fabrication of a submicrometer grain size in the Zn-22% Al alloy by subjecting the samples to intense plastic straining in torsion under high pressure (5 GPa) at room temperature. Observations after straining revealed a heterogeneous microstructure with grain sizes in the range of 0.1–0.5 μ. As a result of the low melting temperature of the alloy, the high internal stresses introduced by torsion straining are relaxed and the grain boundaries are close to an equilibrium configuration. (Author)

A96-44508 Influence of particle size and volume percent of flaky Mo particles on the mechanical properties of Al_2O_3/Mo composites. Y. WAKU, M. SUZUKI, Y. ODA, and Y. KOHTOKU (Ube Industries, Ltd., Yamaguchi, Japan), *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science* (ISSN 1073-5623), Vol. 27A, No. 10, 1996, pp. 3307–3317. 10 Refs. Documents available from AIAA Dispatch.

The influence of particle size and volume percent of Mo particles on flake-forming behavior of Mo powders during a ball milling process and three-point flexural strength and fracture toughness of Al_2O_3 composites reinforced with flaky Mo particles have been investigated. The flake-forming behavior of Mo powders mixed with Al_2O_3 powders becomes prominent with increasing Mo particle size, while remaining almost independent of Mo volume percent. The microstructure of the composites reinforced with flaky Mo particles is anisotropic, depending on the arrangement of these Mo particles in the Al_2O_3 matrix. The microdispersion of flaky Mo particles contributes remarkably to an increase in both flexural strength and fracture toughness. The flexural strength increases with decreasing Mo particle size, while the fracture toughness increases with increasing Mo particle size, which corresponds to an increase of the flake-forming tendency of these particles. Furthermore, the flexural strength and fracture toughness can be simultaneously improved by increasing the volume fraction of flaky Mo particles. The microstructural observations indicate that the improvement in strength may be attributed to a grain-refining effect due to inhibition of grain growth of the matrix by the presence of Mo particles. (Author)

A96-44503 Solidification of undercooled Fe-Cr-Ni alloys. II—Microstructural evolution. T. KOSEKI (Nippon Steel Corp., Chiba, Japan) and M. C. FLEMINGS (MIT, Cambridge, MA), *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science* (ISSN 1073-5623), Vol. 27A, No. 10, 1996, pp. 3226–3240. 19 Refs. Documents available from AIAA Dispatch.

Results are reported on microstructures of Fe-Cr-Ni alloys, solidified over a range of undercoolings and quenched during or after recalescence. Alloys studied contained 70 wt% Fe and with Cr varying from approximately 15 to 20 wt%. The three lower Cr alloys were hypoeutectic; the two higher Cr alloys were hypereutectic. Results obtained are in agreement with predictions based on thermal analyses previously presented; they confirm and extend the understanding gained in that work. The primary phase to solidify in the hypoeutectic alloys is bcc when undercooling is greater than an amount which decreases with increasing Cr content. At the lower Cr contents, the stable fcc phase then forms by solid-state transformation of the metastable phase and its subsequent engulfment by additional fcc. At the higher Cr content, transformation is by a peritectic-like reaction in the semisolid state, except near the surface at higher undercoolings where the transformation is massive. In the hypereutectic alloys, primary solidification at all undercoolings is the stable bcc phase. Partial transformation to fcc occurs in the semisolid or solid state, depending on composition and undercooling. (Author)

A96-44495 Intergranular fracture in some precipitation-hardened aluminum alloys at low temperatures. S. KURAMOTO (Furukawa Electric Co., Ltd., Tochigi, Japan), G. ITOH, and M. KANNO (Tokyo, Univ., Japan), *Metallurgical and Materials Transactions A—Physical Metallurgy and Materials Science* (ISSN 1073-5623), Vol. 27A, No. 10, 1996, pp. 3081–3088. 11 Refs. Documents available from AIAA Dispatch.

Intergranular fracture at low temperatures from room temperature down to 4.2 K has been studied in some precipitation-hardened aluminum alloys. Microscopic appearance of intergranular facets is revealed to be greatly affected by the microstructure adjacent to the grain boundaries (GBs). When large precipitates on GBs and wide precipitation-free zones (PFZs) are present, coalescence of microvoids initiated at the GB precipitates causes the intergranular fracture with dimples. This fracture process is found to be unaffected by deformation temperature. On the other hand, in the presence of fine precipitates on GBs and narrow PFZs, matrix slip localization exerts significant influence on the fracture behavior. At low temperatures, large stress concentration at GBs leads to intergranular fracture, forming sharp ledges on the fracture surfaces, while at room temperature, the dynamic recovery process is thought to relax such stress concentration, resulting in a transgranular 'ductile' rupture. (Author)

A96-43204 Duty cycle and modulation effects in aluminium alloy welding with high power Nd-YAG laser. Y. P. KATHURIA and A. TSUBOI (Laser X Co., Ltd., Ckiryu, Japan), *High-power lasers: Applications and emerging applications; Proceedings of the Conference*, Besancon, France, 1996 (A96-43201 12-36), Bellingham, WA, Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings. Vol. 2789), 1996, pp. 21–27. 13 Refs. Documents available from AIAA Dispatch.

The modulation and duty cycle effects on Al-alloy welding with high power Nd-YAG laser are investigated. Microstructural characterization of the light and heavy duty welds with wave modulation identified differences in the weld morophology. Welding depth, undercut, and strength of fusion zone are discussed as a function of the processing parameters. (Author)

A96-42611 Development of functionally graded sintered hard materials. K. TSUDA, A. IKEGAYA, K. ISOBE, N. KITAGAWA, and T. NOMURA (Sumitomo Electric Industries, Ltd., Itami, Japan), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 45–52. 4 Refs. Documents available from AIAA Dispatch.

Functionally graded materials, made from two different materials with graded composition, have attracted much interest for their ability to exhibit both the characteristics of materials plus new functionality. The idea was applied to the field of hard materials. The developed material consists of a titanium-based ceramic surface layer, a cemented carbonitride core with WC phase, and an

intermediate layer with graded composition. It has a high compressive residual stress of 0.8 GPa imparted to the surface region. When applied to cutting tools, the material has an abrasion resistance and fracture toughness much higher than those of conventional cermets of uniform composition. Because of the graded composition, the surface ceramic layer has high adhesive strength, providing longer life than coated tools in which spalling of the film occurs easily. This new material is made from combining cermet and cemented carbide, and through careful control of sintering conditions. (Author)

A96-41825 Sapphire matrix composites reinforced with single crystal YAG phases. Y. WAKU, H. OHTSUBO, N. NAKAGAWA, and Y. KOHTOKU (Ube Industries, Ltd., Japan), *Journal of Materials Science* (ISSN 0022-2461), Vol. 31, No. 17, 1996, pp. 4663–4670. 15 Refs. Documents available from AIAA Dispatch.

An investigation of fabrication technology on eutectic composites consisting of Al_2O_3 phases and YAG ($Y_3Al_5O_{12}$) phases was carried out by applying the unidirectional solidification process. Unidirectionally solidified eutectic composites consisting of (1 1 0) sapphire phases and (4 2 0) single-crystal YAG phases could be fabricated successfully by lowering a Mo crucible at a speed of 5 mm/h under a pressure of 105 mm Hg of Ar. These eutectic composites have excellent high- temperature properties up to 1973 K. For example, the flexural strength is 360–500 MPa independent of testing temperature from room temperature to 1973 K. Oxidation resistance at 1973 K in an air atmosphere is superior to SiC and Si_3N_4 and the microstructure of these eutectic composites is stable even after heat treatment at 1773 K for 50 h in an air atmosphere. (Author)

A96-41754 Structural relation between a 2D fivefold quasicrystal and crystalline approximants in an Al-Co-Ni-Tb alloy. X. Z. LI and K. HIRAGA (Tohoku Univ., Sendai, Japan), *Journal of Materials Research* (ISSN 0884-2914), Vol. 11, No. 8, 1996, pp. 1891–1896. 19 Refs. Documents available from AIAA Dispatch.

A two-dimensional quasi-crystal with fivefold symmetry and two large-unit-cell crystalline approximants in an Al-Co-Ni-Tb alloy, which were observed in previous studies, are suggested to be composed of the same kind of atom cluster. Some characteristics of the atom cluster can be deduced from a high-resolution electron microscopy image of the Al-Co-Ni-Tb quasi-crystal when the image is associated with a fivefold aperiodic tiling. By using the cut-and-projection method, a quasi-periodic tiling generated by an irrational projection is proposed as an ideal quasi-lattice of the Al-Co-Ni-Tb quasi-crystal; in the meantime, periodic tilings generated by a rational projection present the lattices of the crystalline approximants. (Author)

A96-41748 Processing of a novel multilayered silicon nitride. Y. SHIGEGAKI (Fine Ceramics Research Association, Nagoya, Japan), M. E. BRITO, K. HIRAO, M. TORIYAMA, and S. KANZAKI (Nagoya, National Industrial Research Inst., Japan), *American Ceramic Society, Journal* (ISSN 0002-7820), Vol. 79, No. 8, 1996, pp. 2197–2200. 22 Refs. Documents available from AIAA Dispatch.

A new type of silicon nitride with a layered structure of alternating dense and porous layers was obtained by addition of beta-Si_3N_4 whiskers to the porous layers. The materials consisted of dense layers 60 μ thick and porous layers 40 μ thick, with a final porosity of about 30%. Highly anisotropic shrinkage behavior was observed during sintering. A large addition of whiskers to the porous layers resulted in layers with well-oriented and tightly tangled elongated grains, where porosity is represented by anisotropic shaped pores. (Author)

A96-41724 Hot workability and mechanical properties of a TiB particle reinforced PM beta-titanium matrix composite. T. SAITO, H. TAKAMIYA, and T. FURUTA (Toyota Central Research and Development Labs., Inc., Aichi, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2859–2866. 9 Refs. Documents available from AIAA Dispatch.

A new high-performance beta-titanium alloy-based MMC reinforced with TiB particles has been developed via a low-cost blended elemental powder metallurgy process. The material has a wide-range window for hot-working because a fine beta-grain size could be maintained from 1100 to 1600 K by the pinning effect of the absolutely stable TiB particle dispersion. The MMC has an excellent hot-workability superior to conventional Ti-6Al-4V alloy, and hot-worked MMC shows good mechanical properties: tensile strength and Young's modulus could reach 1900 MPa and 180 GPa, respectively. It also shows wear resistance superior to the well-known wear resistant material Stellite No. 6. Besides the advantages in properties, the material could be made at a low cost, far below that of the conventional titanium alloys made by ingot metallurgy process. This paper describes the hot-workability and mechanical properties of the material and demonstrates some possibilities of application to automobile parts. (Author)

A96-41716 High temperature mechanical properties of in-situ processed Ti_3Al/TiB intermetallic matrix composites. S. EMURA, M. HAGIWARA, and Y. KAWABE (National Research Inst. for Metals, Tsukuba, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2795–2802. 9 Refs. Documents available from AIAA Dispatch.

Ti_3Al-based intermetallic matrix composites (IMCs) reinforced with 10 wt% TiB ceramic particulates have been produced by the blended elemental (BE) powder metallurgy (P/M) method to improve its high-temperature mechanical properties. Pure titanium powder, Nb-Al master alloy powder, and TiB_2 ceramic powder were chosen as starting materials. During sintering, TiB_2 powders react with Ti to form TiB particulates, which were observed dispersing in Ti_3Al matrix. By using finer starting powder and by vacuum-sintering at higher temperature, TiB particulates were found to distribute more homogeneously. Tensile tests were carried out at different temperatures up to 1073 K. Creep tests were also performed. The results demonstrated that the high-temperature mechanical properties of Ti_3Al/TiB composites were superior to those of the unreinforced Ti_3Al intermetallic compounds. (Author)

A96-41694 Influence of microstructure on the fracture processes of powder-processes blended elemental Ti-10V-2Fe-3Al alloys. H. MORI, M. ENOKI, and T. KISHI (Tokyo, Univ., Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2618–2625. 13 Refs. Documents available from AIAA Dispatch.

The influence of microstructure on the fracture processes of powder-process-blended elemental Ti-10V-2Fe-3Al alloys is investigated in detail. The effect of alpha-phase on the fracture processes is discussed. Tensile properties, fracture toughness, and acoustic emission (AE) detected during fracture toughness tests are evaluated. The effect of alpha-phase on crack propagation behavior is also discussed. Optical, scanning, and TEM have been used to characterize the relationship between alpha-phase and crack propagation behavior. It was found that fracture toughness decreased with the increase of aspect ratio of alpha-phase in this alloy system. Fracture units such as microfracture initiation and propagation, which are influenced by alpha-phase morphology, are evaluated from the AE analysis and fractography. These microfracture units are controlled by the deformation of alpha or beta phase and the crystallography of the alpha-beta phase characteristics. It is concluded that the aspect ratio of alpha-phase is most the important microstructural parameter for the control of microfracture processes of the PBE near-beta-titanium alloys. (Author)

A96-41687 Development of high-performance Ti-Al-Fe alloy series. H. FUJII, K. TAKAHASHI, S. SOEDA (Nippon Steel Corp., Futtsu, Japan), and M. HANAKI (Toho Titanium Co., Ltd., Chigasaki, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2539–2546. 13 Refs. Documents available from AIAA Dispatch.

The ternary Ti-Al-Fe alloy series having excellent tensile and fatigue properties was developed. The tensile strength of the series ranges from 700 to 1100 MPa depending on the concentrations of Al and Fe. The effect of the concentrations of the interstitial elements on tensile properties was also investigated. Among the alloys in the series, Ti-3.5Al-1Fe and Ti-5.5Al-1Fe are expected to be the substitutes for Ti-3Al-2.5V and Ti-6Al-4V, respectively. Ti-5.5Al-1Fe-0.36(O + 2.77N), which is one of the representative alloys, has higher tensile and fatigue properties and a little better hot workability than Ti-6Al-4V. Some precautions on the embrittlement during exposure at intermediate temperatures are also suggested. (Author)

A96-41682 The effect of silicon addition on the microstructure and the aging behavior of Ti-3Al-8V-6Cr-4Mo-4Zr alloy. F. MORITO, S. MUNEKI, J. TAKAHASHI, and T. KAINUMA (National Research Inst. for Metals, Tsukuba, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2494–2501. 10 Refs. Documents available from AIAA Dispatch.

The effect of a small amount of silicon addition on the microstructure and the aging behavior of Ti-3Al-8V-6Cr-4Mo-4Zr alloy was investigated. With an increase of silicon addition, a number of fine silicide particles were produced at relatively lower annealing temperature. Silicide particles suppressed grain growth and recrystallization, resulting in a significant grain refinement. Fine silicide precipitates with a diameter of 0.2 μ or less were uniformly dispersed in the alloy matrix and were identified as Ti_5Si_3 type. At rather lower temperature, such as 673 K, age-hardening by alpha-phase precipitation was accelerated in the beta matrix without silicon addition. Furthermore, PFZ was clearly recognized near grain boundaries. These facts mean that quenched-in vacancies played an important role in aging behavior. But the age-hardening was suppressed with an increase of silicon content, indicating that the silicon in solid solution and retained silicides were effective as the trapping sites of vacancies. However, the age-hardening was enhanced by a small amount of silicon addition at rather higher temperatures such as 773 and 873 K. Alpha-phase precipitation preferentially occurred both at interfaces of fine silicide particles and at grain boundaries.

A96-41651 Development of high performance heat resistant near-alpha titanium alloy compressor disk. T. NODA, M. OKABE, S. ISOBE (Daido Steel Co., Ltd., Nagoya, Japan), S. NISHIKIORI, and H. HATTORI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tanashi, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2258–2264. 6 Refs. Documents available from AIAA Dispatch.

For near-alpha DAT54, Ti5.8Al-4Sn-3.5Zr-2.8Mo-0.7Nb-0.4Si-0.06C, designed as a compressor disk alloy, the optimum primary alpha was defined as 17 vol% in the transformed beta. Full-scale disks in the alloy were successfully manufactured by melting via PPC-VAR-VAR and thermomechanical processing via GFM press-die forge. The solution treatment for the above structure contributed to the proper balance of the LCF life with the creep strength of the disks up to 540°C. (Author)

A96-41605 Dual-structure compressor disk of heat-resistant titanium alloy. S. NISHIKIORI, H. HATTORI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), T. NODA, M. OKABE, and S. ISOBE (Daido Steel Co., Ltd., Nagoya, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1646–1653. 4 Refs. Documents available from AIAA Dispatch.

The near-alpha alloy DAT54 (Ti-5.8Al-4.0Sn-3.5Zr-2.8Mo-0.7Nb-0.4Si-0.06C) has been developed as a forging material for high temperature structural use in aircraft turbine engines. This alloy is characterized by a high amount of Mo addition, which improves strength without reducing ductility. This heat-resistant Ti-based alloy has great potential for use in jet engine applications up to 550°C. We have developed a manufacturing process for this alloy which can supply sound billets and disks on the actual operation level. We have investigated the possibility of using this alloy with dual-structure for the compressor disk application on a jet engine. Several heat treatment processes have been examined to produce the dual-structure sample. It is shown that the partial high-frequency induction heating process makes it possible to manufacture 400 mm diameter class disks with dual-structure on the production scale. In addition, the effects of the volume fraction of the equiaxed primary alpha grain on mechanical properties have been investigated in connection with optimizing microstructure in the bore section of the disk.

A96-41569 Microstructure and fracture properties of annealed SP-700. A. OGAWA, K. MINAKAWA, and S.-I. TAKAGI (NKK Corp., Kawasaki, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1251–1258. 11 Refs. Documents available from AIAA Dispatch.

Tensile properties and fracture toughness of SP-700 are investigated in a wide range of annealing conditions. The present study reveals that in the alpha + beta microstructures annealed above 816°C, tensile strength is significantly increased with increasing annealing temperature. TEM study exhibits that the observed increase in tensile strength is due to fine alpha phase precipitated in the beta matrix during air cooling. The highest fracture toughness is found in the beta annealed microstructure at the great expense of ductility. It is also found that alpha + beta duplex annealing greatly improves the fracture toughness at the strength level of 950–980 MPa. Factors and mechanisms which control the fracture toughness of annealed SP-700 are discussed through microstructure and crack extension processes. (Author)

A96-41555 Fatigue crack initiation site in titanium alloys at cryogenic temperatures. K. NAGAI, T. YURI, and O. UMEZAWA (National Research Inst. for Metals, Tsukuba, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1139–1146. 7 Refs. Documents available from AIAA Dispatch.

In titanium alloys, subsurface or internal initiation of stage I crack in high cycle fatigue occurs more frequently at cryogenic temperature. The initiation has a microstructural origin like alpha phase cracking. The present paper compares the initiation site distribution among Ti-64, Ti-525, and a high purity austenitic steel in fatigue at 4 K. In Ti-64, the sites were seen only near the surface. In Ti-525, the initiation was more interior. In the austenitic steel, on the other hand, the initiation probability was even over the specimen section. These differences are discussed in terms of the probability of the microstructural origins in the specimen section. (Author)

A96-41554 A microstructural study of fatigue failure in titanium. M. SUGANI, N. TANAKA, E. SAKUMA, and T. SATAKE (Yamagata Univ., Yonezawa, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1131–1138. 12 Refs. Documents available from AIAA Dispatch.

To understand the fatigue failure micromechanisms of titanium, the fatigue behavior of an annealed titanium plate (973 K for 2 h) has been studied on the longitudinal (LT) and transverse (TL) specimens. The specimens were subjected to alternate plane bending in air and in a vacuum. In air, the S-N curve for the TL specimen was slightly higher than that for the LT one, and the process zone wake of a main crack was less damaged in the TL specimen than in the LT one. In a vacuum, S-N curves and fatigue deformation in the process zone wake were much the same both in quality and in quantity for the specimens. Deformation twins were observed only in the specimens tested in air. The results obtained were connected with higher slip activity caused at a crack tip by internal heating under cyclic stressing in a vacuum. (Author)

A96-41538 Tensile properties of cold-worked and high-low temperature duplex-aged Ti-15(V, Mo)-3Cr-3Sn-3Al alloys. K. ITO, T. DEGUCHI, and H. MORIOKA (Tokyo, Univ., Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1004–1010. 6 Refs. Documents available from AIAA Dispatch.

Vanadium was partly replaced by slower diffusing molybdenum in order to examine further effects of duplex aging. Alloys with beta-transus designed to be equal to that of the conventional Ti 15-3 alloy were prepared for bars. They were solution-treated, cold-swaged, aged first at 873–1023 K and then at 673–723 K, and tested at room temperature. This duplex aging (CWDA) is found to be better than a single aging after cold working (CWA) in the balance of strength and ductility. The ductility, however, decreases and the difference between CWDA and CWA becomes smaller with the increasing replacement. A desirable nature of the CWDA treatment is suggested to exist in the proper recovery of the dislocation structure and/or formation of a microduplex structure by the first aging. (Author)

A96-41531 Improvement of strength and fracture toughness in isothermally forged Ti-10V-2Fe-3Al. T. MAEDA and M. OKADA (Sumitomo Metal Industries, Ltd., Amagasaki, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 948–955. 11 Refs. Documents available from AIAA Dispatch.

Investigations have been made on the effects of processing factors consisting of isothermal forging and subsequent heat treatments on strength, ductility, and fracture toughness in Ti-10V- 2Fe-3Al with the aim of improving the balance of these mechanical properties. An increase of the temperature in isothermal forging in the alpha + beta phase region with selected heat treatments resulted in an increase of fracture toughness under the same level of strength, which is mainly attributed to the coarsening of beta subgrains. Higher aging temperature led to the growth of precipitated alpha, which also contributed to an increase of fracture toughness but with significant loss of strength. The microstructure/property relationship has been discussed, including phase chemistry, and it is suggested that controlling the sizes of beta subgrain and aging alpha is essential for obtaining well-balanced mechanical properties. (Author)

A96-41500 Superplasticity and post-SPF properties of SP-700. A. OGAWA (NKK Corp., Tokyo, Japan), H. IZUMI (NKK Corp., Kawasaki, Japan), and K. MINAKAWA (NKK Corp., Tokyo, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 588–595. 19 Refs. Documents available from AIAA Dispatch.

Superplasticity and post-SPF (superplastic forming) properties of SP-700 (Ti-4.5Al-3V-2Mo-2Fe) were studied. 2-mm thick SP-700 sheet was superplastically formed to a 'bathtub-shape' part of 75 mm (depth) × 250 mm × 400 mm at 1073 K using 99.99% pure Ar gas. Tensile and fatigue strength as well as microstructure were examined for the superplastically formed part. It was revealed that minimal levels of grain growth and alpha-case formation occurred during the superplastic forming of SP-700 sheet. It was also found that superplastic forming reduced tensile and fatigue strength as compared with SP-700 in the mill annealed condition. However, the mechanical properties of the superplastically formed SP-700 product can be considerably improved by direct aging. The grain growth behavior and the effects of alpha–case on the post-SPF properties are discussed in detail. (Author)

A96-41499 Mechanical properties of the intermetallic compounds $Al_3(Ti(1-x)M(x))$. G. ITOH, K. KITA, and M. KANNO (Tokyo, Univ., Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 581–587. 13 Refs. Documents available from AIAA Dispatch.

Mechanical properties of some titanium trialuminides, $Al_3(Ti(1-x)M(x))$, having L1(2) and/or D0(22) structure were examined (where M is Sc, Er, or Lu, and $x = 0, 0.25, 0.5$, or 0.75). Ingots weighing about 50 g were melted in an argon plasma arc furnace. Microstructural observation confirmed the occurrence of an L1(2) phase in all M bearing alloys in the as-cast condition. Compression tests were carried out to roughly assess the ductility of these alloys in the as-cast condition at temperatures ranging from room temperature to 800°C. The results showed that Sc alloying was most effective in increasing the ductility of Al_3Ti at any of the temperatures used, which was primarily attributable to an increase in the volume fraction of L1(2) phase. A preliminary study of the relationship between the mechanical properties, microstructure, and processing route showed that isothermal forging at 1175°C by 45% caused recrystallization during the deformation and significantly increased the room temperature ductility of a cast Al-26 at.% Ti-9 at.% Cr alloy consisting primarily of the L1(2) phase. This was attributed to the expected diminution of pores and the observed modification of the structure. (Author)

A96-41476 Microstructures and mechanical properties of blended elemental powder metallurgy Ti_2AlNb intermetallics. S. EMURA (National Research Inst. for Metals, Tsukuba, Japan), J. LIU (Chiba Inst. of Technology, Japan), M. HAGIWARA, Y. KAWABE (National Research Inst. for Metals, Tsukuba, Japan), and A. OKADA (Chiba Inst. of Technology, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 404–410. 9 Refs. Documents available from AIAA Dispatch.

Ti:AlNb intermetallics containing ordered orthorhombic O phase have been produced by the blended elemental (BE) P/M method. Extralow chlorine pure titanium powder and Nb-Al master alloy powder were blended, compacted, sintered, and hot isostatic pressed (HIP'ed) to make the intermetallics. By using finer starting powder (45 μ) and by vacuum sintering at higher temperature (1773 K), master alloy powder diffused sufficiently, and homogeneous intermetallics could be obtained. Microstructural observation and X-ray diffraction analysis were carried out on the materials both as-HIP'ed and heat-treated at 1173 K for 36 ks after HIP'ing. Tensile tests at temperatures up to 1073 K and room temperature fatigue tests were also performed. Heat-treated material had a more homogeneous microstructure and less of the beta phase and showed better ductility and fatigue strength than the as-HIP'ed material. (Author)

A96-41469 Influence of composition on creep of alpha-two Ti_3Al polycrystals. K. MARUYAMA, J.-I. KOIKE, and H. OIKAWA (Tohoku Univ., Sendai, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World*

Conference on Titanium, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 348–355. 11 Refs. Documents available from AIAA Dispatch.

Compressive creep tests under constant stress (80–500 MPa) were done in an argon atmosphere on single-phase material with equiaxed grains (20–150 μ) containing 34.0, 27.5, and 24.0 mol% Al over the temperature range from 1050 to 1250 K. Creep behavior can be classified into three regions. In each region, the minimum creep rate shows characteristic dependence on temperature, stress, and grain size. Creep parameters have been determined on 34.0 and 27.5 mol% Al alloys. The relative creep strength is discussed based on these results. Under high stresses, the off-stoichiometric material is moderately stronger than the near-stoichiometric material. Under low stresses, however, the creep strength becomes almost independent of composition.

A96-41468 Fracture and fatigue crack growth behavior in a Ti_3Al based aluminide at ambient and elevated temperatures. K. TAKASHIMA (Kumamoto Univ., Japan), M. T. COPE (Rolls-Royce, PLC, Derby, United Kingdom), and P. BOWEN (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 340–347. 13 Refs. Documents available from AIAA Dispatch.

Fracture toughness and fatigue crack growth behavior of a Ti-25Al-10Nb-3V-1Mo (at.%) alloy with a primary equiaxed alpha-2 + transformed beta microstructure has been investigated at temperatures of 20, 400, and 700°C both in air and in vacuum. Although a valid K(IC) was obtained at room temperature only, fracture toughness values increase with increasing temperature. Fracture surfaces show cleavage fracture at ambient temperature, a mixture of cleavage and ductile fracture at a test temperature of 400°C, and large microvoids initiated at primary alpha-2 particles at a test temperature of 700°C. Under cyclic loading at room temperature, crack extension across alpha-2 particles and alpha-2 laths in transformed beta regions occurs in transgranular manner. In transformed beta regions, cracks are also deflected along interfaces between the alpha-2 laths. At elevated temperatures, fatigue crack growth rates in air were higher than those in vacuum by approximately an order of magnitude. At 400°C, primary alpha-2 particles still cleave under cycling loading, and the surrounding transformed beta regions exhibit some microductility. At 700°C, the fracture surface was flat, and fatigue cracks grew across primary alpha-2 particles transgranularly. (Author)

A96-41463 Fracture characteristics and slip behaviors related to microstructures in Ti-24Al-11Nb (at.%). M. NINOMI, T. KOBAYASHI, M. IWAI, T. HIROTA (Toyohashi Univ. of Technology, Japan), J. C. WILLIAMS (General Electric Co., Aircraft Engine Div., Cincinnati, OH), and A. W. THOMPSON (Carnegie Mellon Univ., Pittsburgh, PA), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 302–309. 6 Refs. Documents available from AIAA Dispatch.

Fracture characteristics of Ti_3Al-Nb, Ti-24Al-11Nb (at.%) were related to the microstructures based on the results of tensile and fracture toughness tests. Fracture mechanisms were also investigated. Fracture toughness, Jlc, increases when microcracks are formed at the interfaces of colonies or acicular alpha-2 in beta solutionized and furnace cooled materials. The microcracks are formed by the coarse and big slip bands which are activated widely near the crack tip as a result of the formation of colonies. The crack propagation resistance, T(mat), increases with increasing crack deflection and shear ligaments in addition to microcracks. Jlc and T(mat) decrease with increasing precipitations of fine alpha-2 and beta during air cooling in alpha-2 + beta solutionized and air cooled materials. The blunting of the crack tip is inhibited because the deformability of beta is inhibited by the fine precipitated alpha-2. The microstructure of equiaxed alpha-2, which is obtained by solutionizing at 1313 K for 7.2 ks followed by water quenching, gives the best balance of strength, elongation, and fracture toughness. (Author)

A96-41462 Phase equilibria among alpha, alpha-2, beta and gamma phases in ternary Ti-Al-X systems at elevated temperatures. M. TAKEYAMA, Y. KATO, and M. KIKUCHI (Tokyo Inst. of Technology, Japan), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 1, 1995 (A96-41426 11-26), London, Inst. of Materials, 1996, pp. 294–301. 20 Refs. Documents available from AIAA Dispatch.

Phase equilibria among alpha, alpha-2, beta(B2), and gamma phases in a Ti-38 at.% Al-6 at.% Nb alloy at temperatures below 1200 C have been examined. The alloy shows the alpha-2 single phase at 1100 and 1150°C, whereas it exhibits three phases of alpha, alpha-2, and B2(beta) in equilibrium at 1200°C. The B2 phase contains 1.5 at.% more niobium than the other two phases, and the alpha phase contains 1.5 at.% more aluminum than the alpha-2 phase. The addition of niobium to Ti-Al binary alloys stabilizes the alpha-2 phase and raises the reversible alpha-alpha-2 order/disorder transition temperature, resulting in an isolated island of the alpha-2 single phase region between the alpha and B2 single phase regions in the Ti-Al-Nb system at 1200°C. The existence of the three-phase alpha + alpha-2 + B2(beta) coexisting region suggests that the following peritecto-eutectoid reaction would take place with decreasing temperature: (alpha + alpha-2 + beta) + (alpha + beta + gamma) – (alpha-2 + beta + gamma) + (alpha + alpha-2 + gamma). (Author)

German Aerospace Literature
This month: *Materials Microstructures*

A96-44910 Microstructural stability under creep conditions of two Al-Cu-Mg-Ag alloys. B. SKROTZKI (Bochum, Ruhr-Univ., Germany), H. HARGARTER, and E. A. STARKE JR. (Virginia, Univ., Charlottesville), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 1245–1250. 10 Refs. Documents available from AIAA Dispatch.

The effect of creep conditions on the microstructural stability of two Al-Cu-Mg-Ag alloys in the T8 temper has been investigated. The microstructure of the crept samples was very stable with no significant change in the volume fraction, number density, diameter, and thickness of the matrix precipitates when compared to the initial T8 temper. In addition, no significant change in grain boundary precipitates occurred under the creep conditions of this study as indicated by the amount of intergranular fracture before and after creep. (Author)

A96-44786 On the transition of solidification mechanisms in highly undercooled germanium. D. LI, K. ECKLER, and D. M. HERLACH (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 517–522. 10 Refs. Documents available from AIAA Dispatch.

Large undercoolings of up to Delta-T = 426 K for pure germanium were reproducibly obtained using the containerless EM levitation technique. The crystal growth behavior and grain structure developments of Ge are studied as a function of the bulk undercooling, Delta-T. Three undercooling regions of different growth behavior and morphologies are identified: 1) lateral growth (LG) for Delta-T less than 300 K (the typical lamellar twins (111) 211 line were grown at the lower end of this region, whereas, at the higher end, a mixed structure appeared); 2) continuous growth (CG) beyond a threshold undercooling (the crystal growth velocity, V, increases rapidly at Delta-T = 300 K, which is evidence for a transition from LG to CG); and 3) rapid crystal growth (homogeneous grain refinement was observed in bulk pure Ge samples when V is not less than 0.8 m/s for Delta-T not less than 400 K. In the CG range, the measured growth velocities agree well with slightly modified, current dendrite growth theory. (Author)

A96-44767 Evidence for a coupled growth of the properitectic alpha-Ti and the peritectic-TiAl in binary titanium aluminides. J. LAAKMANN, P. BUSSE, S. RUELLENRATH, and F. MEISSEN (ACCESS, Aachen, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 355–362. 13 Refs. Documents available from AIAA Dispatch.

Binary titanium aluminides with concentrations in the range of 48–54 at.% aluminum were solidified directionally using a Bridgman unit. The temperature gradient exceeded 17 K/mm, and the withdrawal velocity v was between 0.025 and 10 mm/min. Alloys with concentrations up to 52 at.% aluminum solidify in primary alpha-dendrites with interdendritic gamma-TiAl. Decreasing the withdrawal velocity or the aluminum concentration suppresses the creation of secondary dendrite arms and coarsens the microstructure. A completely different microstructure is exhibited by alloys with 54 at.% Al at very low solidification velocities. This microstructure consists of two phases growing parallel to the growth direction. To explain the above-mentioned behavior an extended model of stationary peritectic reaction, including gravity-driven effects like sedimentation and convection, is discussed. A directional solidification experiment under reduced gravitation is proposed to validate this model. (Author)

A96-44759 Directional solidification of Al-Al_3Ni eutectic alloys in an aerogel furnace. T. BUCHHOLZ, J. ALKEMPER (DLR, Inst. fuer Raumsimulation, Cologne, Germany), K. MURAKAMI (NASDA, Tsukuba, Japan), and L. RATKE (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 291–296. 9 Refs. Documents available from AIAA Dispatch.

Directional solidification experiments of eutectic Al-Al_3Ni alloyshave been performed using a new facility named ARTEMIS. This facility allows good control of the solidification parameters, especially the velocity of the solidification front and the temperature gradient ahead of the solid-liquid interface. On vertical cuts through the samples the distance of the Al_3Ni fibers lambda was measured and plotted vs the solidification velocity. The results fit the Jackson and Hunt prediction of lambda*nu 2 = const. The microstructure of the solidified Al-Al_3Ni alloys shows clear differences between samples solidified with constant and those solidified with varying solidification parameters. These differences are analyzed with various techniques and are discussed. (Author)

A96-44755 Numerical modelling of microstructure evolution in castings of immiscible alloys. S. DRESS and L. RATKE (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 265–270. 10 Refs. Documents available from AIAA Dispatch.

The discrete multiparticle approach (DMPA), a newly developed numerical simulation technique, is presented together with one application of it: the evaluation of the results from a D-2 experiment on immiscibles. The DMPA enables the numerical modeling of the phase separation and solidification of alloys that are immiscible as melts like aluminum, lead, or bismuth. (Author)

A96-44754 Evolution of the microstructure during solidification of immiscible alloys. L. RATKE (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 251–264. 33 Refs. Documents available from AIAA Dispatch.

This paper discusses some recent experimental and theoretical progress on microstructure evolution during solidification of alloys exhibiting a miscibility gap in the liquid state, revealing the importance of all physical processes that occur in a region ahead of the solid/liquid interface where the liquid is thermodynamically in the two-phase liquid regime. These processes are nucleation of the minority phase as drops, their diffusional growth, Stokes sedimentation, Marangoni motion, and coagulation of drops. Comparison of experimental results under Earth and reduced gravity conditions with theoretical models reveal that these processes occurring while passing the miscibility gap seems to be of more importance than the interaction of the second phase drops with the solid/liquid interface. Advantages and limitations of the theoretical modeling based on population dynamics are discussed. (Author)

A96-44751 Three dimensional observation of directional solidification front by forced decanting. D. MA and P. R. SAHM (Aachen, Rheinisch-Westfaelische Technische Hochschule, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 229–234. 13 Refs. Documents available from AIAA Dispatch.

Two procedures of 'forced decanting' to separate residual melt from solidification front are described. During directional solidification the residual melt can be rapidly removed by means of centrifugal forces, or sucked out under a negative pressure. In the experiments with a technical Al-Si alloy the dendritic as well as the cellular structure has been well exposed. These results make it possible to observe the morphology of the solidification front and the microstructural arrangement at the liquid-solid interface in three-dimensional. From the appropriate photographs all important structure parameters can be easily determined without expensive metallographic preparations.

A96-44750 Microstructural evolution during directional solidification of superalloy CMSX-6. D. MA and P. R. SAHM (Aachen, Rheinisch-Westfaelische Technische Hochschule, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 223–228. 13 Refs. Documents available from AIAA Dispatch.

The microstructural evolution of the superalloy CMSX-6 during directional solidification is investigated in detail. The analysis of the transverse sections within the mushy region yields the solidification sequence and the solid fraction f(s) against the temperature decrease. The formed microstructure is characterized in different zones. By means of a special treatment various theoretical models are applied to calculate the f(s) variation for the multicomponent system used. In comparison with experimental measurement a reasonable description is achieved. (Author)

A96-44747 Instability of coarse microstructures during equiaxed growth. M. RETTENMAYR and O. POMPE (Darmstadt, Technical Univ., Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 201–208. 6 Refs. Documents available from AIAA Dispatch.

Al-6.8 wt% Cu samples were held in the mushy zone at a fraction of solid of 50% for 5000 s and then cooled/quenched with different cooling rates. The initial particles formed during the isothermal holding period grow with an unstable interface during the quenching process. Fine cells and dendrites are formed on the surface of the primary alpha particles. At low cooling rates, if the solutal boundary layers of neighbored particles overlap, no solutal instabilities are seen. Measurements of the intercept length in the quenched former liquid and correlation thereof with the solutal boundary layer show good qualitative agreement for the conditions of cell formation and 'stable' growth, respectively. There is also good quantitative agreement for measured and calculated cell spacings. (Author)

A96-44731 Chill casting of Al-Pb- and Al-Bi-alloys in aerogel crucibles during a parabolic flight. G. KOREKT and L. RATKE (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 81–87. 9 Refs. Documents available from AIAA Dispatch.

Hypermonotectic Al-Pb and Al-Bi alloys were solidified on Earth under normal gravity and under reduced gravity conditions of a parabolic flight. The cast microstructure obtained in a reduced gravity environment is dominated by Marangoni-motion of the Pb- or Bi-droplets. Samples processed under 1-g conditions are evidently dominated by Stokes settling of the droplets. A theoretical model is presented treating the microstructure evolution as a concurrent action of nucleation, diffusional growth, and Marangoni-motion of Pb- and Bi-droplets. The theoretical prediction for the volume content of Pb and Bi agrees reasonably well with the experiments. The biggest observable drop radius as a function of position in the sample agrees with the theoretical prediction if collision and coagulation events are taken into account. (Author)

A96-44727 Grain refinement in solidification of undercooled Ni-Cu melts. K. ECKLER, M. SCHWARZ (DLR, Inst. fuer Raumsimulation, Cologne, Germany), A. KARMA (Northeastern Univ., Boston, MA), and D. M. HERLACH (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 45–50. 12 Refs. Documents available from AIAA Dispatch.

The microstructures of bulk Ni-Cu samples solidified from the undercooled melt are investigated. High levels of undercoolings were attained by containerless processing in an EM levitation facility. At both high and low undercoolings

reached prior to nucleation, a grain-refined equiaxed microstructure is formed, whereas for intermediate undercoolings a coarse dendritic microstructure is observed. The transitions between the microstructures take place quite abruptly at critical values Delta-T* of the undercooling. The dependence of the values of Delta-T* on the composition is studied, leading to the construction of a microstructure-selection map for the Ni-Cu system. The results are discussed within the scope of a new model for grain refinement featuring the fragmentation of the primary dendrites. (Author)

A96-44479 Influence of molybdenum silicide additions on high-temperature oxidation resistance of silicon nitride materials. H. KLEMM, K. TANGERMANN, C. SCHUBERT, and W. HERMEL (Fraunhofer-Inst. for Ceramic Technologies and Sintered Materials, Dresden, Germany), *American Ceramic Society, Journal* (ISSN 0002-7820), Vol. 79, No. 9, 1996, pp. 2429–2435. 23 Refs. Documents available from AIAA Dispatch.

The influence of additions of $MoSi_2$ on the microstructure and the mechanical properties of Si_3N_4 material, with Nd_2O_3 and AlN as sintering aids, was studied. The composites, containing 5, 10, and 17.6 wt% $MoSi_2$, were fabricated by hot pressing. All materials exhibited a similar phase composition, detected by X-ray diffractometry. Up to $MoSi_2$ additions of 10 wt%, mechanical properties such as strength, fracture toughness, or creep at 1400°C were not affected significantly, in comparison to that of monolithic Si_3N_4. The oxidation resistance of the composites, in terms of weight gain, degraded. After 1000 h of oxidation at 1400 and 1450°C in air, a greater weight gain (by a factor of approximately three) was obtained, in comparison to that of the material without $MoSi_2$. Nevertheless, after 1000 h of oxidation, the degradation in strength of the composites was considerably less severe than that of the material without $MoSi_2$. An additional layer was formed, caused by processes at the surface of the Si_3N_4 material, preventing the formation of pores, cracks, or glassy-phase-rich areas, which are common features of oxidation damage in Si_3N_4 materials. (Author)

A96-44467 Microstructure development in in situ reinforced reaction-bonded aluminum niobate-based composites. D. E. GARCIA, R. JANSSEN, and N. E. CLAUSSEN (Hamburg-Harburg, Technische Univ., Hamburg, Germany), *American Ceramic Society, Journal* (ISSN 0002-7820), Vol. 79, No. 9, 1996, pp. 2266–2270. 21 Refs. Documents available from AIAA Dispatch.

Reaction-bonded aluminum niobate-based composites with tailorable microstructures were fabricated through controlled nucleation and growth of needlelike $AlNbO_4$ grains. Equiaxed to highly elongated grains were obtained by different heat treatments at 1340 and 1400°C in air. SEM observations revealed that increasing the heating rate promoted the development of large, homogeneously distributed needlelike grains. Because of the elongated nature of the $AlNbO_4$ grains and the high residual stresses at the interface, enhanced crack wake bridging occurred. This bridging accounted for the observed increase of fracture toughness. (Author)

A96-43614 High-Ni Al-Ni-Co decagonal phase. B. GRUSHKO and D. HOLLAND-MORITZ (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Scripta Materialia* (ISSN 1359-6462), Vol. 35, No. 10, 1996, pp. 1141–1146. 19 Refs. Documents available from AIAA Dispatch.

As-cast and annealed $Al_{71}Ni_{24}Co_5$ samples were examined by scanning and transmission electron microscopy, X-ray diffraction, and energy dispersive X-ray analysis. The results indicate the presence of a stable decagonal phase (D-phase) at Ni concentrations as high as 24–45%, which is close to that in the Al-Ni-Fe D-phase. It is found that the decagonal structure can be maintained at this composition by quenching. XRD and electron diffraction reveal a close similarity between both D-phases.

A96-42633 Structure and properties of hardmetal-like coatings prepared by thermal spray processes. L.-M. BERGER, W. HERMEL (Fraunhofer Inst. of Ceramic Technologies and Sintered Materials, Dresden, Germany), P. VUORISTO, T. MANTYLA (Tampere Univ. of Technology, Finland), W. LENGAUER, and P. ETTMAYER (Vienna Univ. of Technology, Austria), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 443–450. 15 Refs. Documents available from AIAA Dispatch.

Thermal spray processes represent an important group of surfacing technologies to produce hardmetal-like coatings for wear protection. WC with cobalt or nickel (often alloyed with chromium) binders and Cr_3C_2-NiCr are the most common systems used in these technologies. The structures and the properties of the coatings depend strongly on composition, on the technology of spray powder preparation, and on the spray process parameters. The service conditions for the cutting applications and for the coatings are quite different. Therefore, the development of new hardmetal systems for coating applications has to take into account the specific process and service conditions. (Author)

A96-42623 Limited fatigue lives of uncoated and coated hardmetals under cyclic loads. U. SCHLEINKOFER, H. G. SOCKEL, P. SCHLUND, P. KINDERMANN, R. SCHULTE, J. WERNER (Erlangen-Nuernberg, Univ., Erlangen, Germany), K. GOERTING, and W. KEINRICH (Kennametal Hertel AG, Mistelgau, Germany), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 239–246. 8 Refs. Documents available from AIAA Dispatch.

The lifetime and reliability of cutting tool materials in technical application under cyclic loads is limited by fatigue. In the past, the materials behavior under cyclic load conditions has been largely neglected. Recent investigations of the authors have shown that cutting tool materials exhibit strong fatigue effects under cyclic load conditions. The damage processes in fatigue lead to reduced lifetimes with increasing stress amplitudes. New investigations on coated and uncoated materials modified in composition and microstructure yield access to information about the lifetime-limiting microstructural processes. The microstructural studies were performed by TEM, SEM, and SAM. This paper summarizes the present knowledge about the mechanical behavior of hard metals under monotonically increasing and cyclic loads without and with coatings and discusses first results concerning the fatigue at higher temperatures. (Author)

A96-42614 Microwave sintering of hardmetals and ceramics. M. WILLERT-PORADA, T. GERDES (Dortmund, Univ., Germany), K. ROEDIGER, (Widia GmbH, Essen, Germany), and H. KOLASKA (Fachverband Pulvermetallurgie, Hagen, Germany), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 69–76. 14 Refs. Documents available from AIAA Dispatch.

The application of microwave radiation as a heat source for sintering of powder metallurgical products is described for carbide-strengthened oxide ceramics and hardmetals. Besides microwave sintering of these materials, examples of microwave reaction sintering are presented. The results illustrate not only the potential of microwave sintering for a major improvement of the sintering process itself, but also the prospective capability of quality improvement for traditional cemented carbides, as well as the development of new hard materials with, e.g., extremely refined microstructures. (Author)

A96-42612 Grain size control in TiC and ZrC syntheses. L.-M. BERGER, and E. LANGHOLF (Fraunhofer Inst. of Ceramic Technologies and Sintered Materials, Dresden, Germany), *Advances in hard materials production; Proceedings of the 1996 European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, pp. 53–60. 20 Refs. Documents available from AIAA Dispatch.

In this paper the influence of the type of carbon on the carbothermal reduction of TiO_2 and ZrO_2 has been studied. It is shown that the reaction can be divided into three steps and that the reaction rate of every step depends on the type of carbon. No type of carbon investigated in this work shows an optimum behavior in all three reaction steps. A CO/CO_2 transport mechanism is the predominant mechanism for the mass transfer. The grain size of the carbides can be controlled by selecting optimum oxide and carbon starting materials in combination with tailored reaction conditions. (Author)

A96-42610 A new a[r]ess to hardmetal parts by injection moulding using a polyacetal base [b]inder system. W. HESSE and P. TRUEBENBACH (BASF AG, Ludwigsha[f]Germany), *Advances in hard materials production; Proceedings of the 19[95] European Conference*, Stockholm, Sweden, 1996 (A96-42607 11-37), Sh[rew]sbury, United Kingdom, European Powder Metallurgy Association, 1996, [pp.] 39–43. Documents available from AIAA Dispatch.

Powder injection mold[ing] is a modern technology for the large-scale production of complex-shaped parts. The BASF-system for powder injection olding, characterized by a polyacetal-based binder and an acid-catalyzed debinding technique, is commercially used to manufacture metal and ceramic parts. The use of a non-oxidizing acid, oxalic acid, widened the spectrum of materials, that can be processed with the BASF-system, to hardmetals containing fine cobalt powders, which are sensitive against oxidation by nitric acid, the commonly used catalyst. The microstructures and mechanical properties of injection-molded hardmetal samples that were debinded with oxalic acid are comparable to those of pressed parts. (Author)

A96-41644 Beta titanium alloys. G. TERLINDE and G. FISCHER (Otto Fuchs Metallwerke, Meinerzhagen, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2177–2194. 51 Refs. Documents available from AIAA Dispatch.

This paper focuses on the processing, microstructures, and properties of beta titanium alloys. An introduction into the metallurgy and processing is given in which the basic microstructures are described as they are influenced by deformation and heat treatment. An attempt is made to correlate processing, microstructures, and properties like tensile properties, fracture toughness, fatigue (HCF) and fatigue crack propagation. It will be shown that the understanding of these partly complex correlations is the necessary key to develop optimized property combinations as well as technically reasonable processing conditions. (Author)

A96-41617 Oxidation behaviour of near-alpha titanium alloys and their protection by coatings. C. LEYENS, M. PETERS, and W. A. KAYSSER (DLR, Inst. fuer Werkstoff-Forschung, Cologne, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 1935–1942. 29 Refs. Documents available from AIAA Dispatch.

Near-alpha titanium alloys suffer from oxide scale formation and severe oxygen embrittlement during service at elevated temperatures. The oxidation behavior of IMI 834 and TIMETAL 1100 depends on the microstructure with the lamellar being more oxidation resistant than the bimodal. Sputtered Ti-Al multilayer and gradient coatings provide excellent oxidation resistance and effectively hinder the embrittlement of the subsurface zone of the substrate alloy. The coatings only slightly influence the creep behavior at 350 MPa but adversely affect the strain rate at 400 MPa. Ultimate tensile strength and yield strength are

not affected by the coatings, but in contrast the ductility is markedly improved by Ti-Al multilayer coatings. (Author)

A96-41606 Influence of thermomechanical processing on mechanical properties of Ti-1100 compressor disks. G. PROSKE, G. TERLINDE, G. FISCHER (Otto Fuchs Metallwerke, Meinerzhagen, Germany), D. HELM, and M. A. DAEUBLER (Daimler-Benz Aerospace AG, Munich, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1654–1661. 11 Refs. Documents available from AIAA Dispatch.

TIMETAL-1100 was chosen to study the influence of different forging conditions and subsequent heat treatments on the mechanical properties of full size compressor disks. Tensile tests at room and elevated temperature, creep resistance, fracture toughness, and low cycle fatigue and high cycle fatigue strength have been investigated in fully lamellar microstructures, since this alloy is recommended for use in lamellar structures. The investigations have shown a pronounced influence of the cooling rate from forging or solution temperature on the mechanical properties, especially on yield stress, tensile strength, and low cycle fatigue strength. Furthermore, it was found that the beta-forged and directly aged conditions have superior mechanical properties compared to beta-forged, beta-solutionized, and aged conditions. (Author)

A96-41587 Processing, microstructure and properties of beta-CEZ. J. O. PETERS, G. LUETJERING (Hamburg-Harburg, Technical Univ., Hamburg, Germany), M. KOREN, H. PUSCHNIK (Boehler Schmiedetechnik GmbH, Kapfenberg, Austria), and R. R. BOYER (Boeing Materials Technology, Seattle, WA), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1403–1410. 12 Refs. Documents available from AIAA Dispatch.

For the beta-CEZ material, some of the important processing parameters for establishing a necklace type of microstructure by through-transus deformation were evaluated with respect to optimizing fracture toughness and yield stress. In addition, the bi-modal type of microstructures which can be produced by conventional alpha + beta processing was evaluated. For the necklace microstructure a high fracture toughness of 68 MPa sq rt m at a yield stress of 1200 MPa was reached in forgings, but the fracture toughness anisotropically dropped to 37 MPa sq rt m in the short transverse direction. For the bi-modal microstructure, an isotropic fracture toughness of 37 MPa sq rt m at a yield stress of 1200 MPa was reached without major difficulties. (Author)

A96-41586 Effect of microstructure and test temperature on fatigue properties of IMI 834. F. TORSTER, A. GYSLER, and G. LUETJERING (Hamburg-Harburg, Technical Univ., Hamburg, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1395–1402. 8 Refs. Documents available from AIAA Dispatch.

The HCF and LCF behavior of fully lamellar and bi-modal microstructures, having between 10 and 40 vol% primary alpha phase, alpha(p), was evaluated in terms of crack nucleation and microcrack propagation at room temperature and 600°C. Crack nucleation appeared to be influenced by the lower basic strength of the lamellar matrix of bi-modal microstructures due to alloy element partitioning and by the much smaller size of the lamellar beta grains of bi-modal structures. At RT the negative effect of alloy element partitioning dominated crack nucleation, resulting in decreasing HCF strength with increasing alpha(p) volume fraction. At high test temperatures the drastically reduced beta grain size with increasing alpha(p) volume fraction resulted in improved HCF and LCF properties of bi-modal microstructures due to the reduced slip length which improved the crack nucleation resistance and due to the increased number of beta grain boundaries and colony boundaries which increased the resistance against propagation of self-initiated microcracks. (Author)

A96-41583 Mechanical properties of duplex microstructures in Ti-2.5Cu. A. STYCZYNSKI and L. WAGNER (Cottbus, Technical Univ., Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1363–1370. 5 Refs. Documents available from AIAA Dispatch.

Duplex (primary alpha phase, alpha(p), in lamellar matrix) microstructures were produced in the age-hardenable beta eutectoid titanium alloy Ti-2.5Cu. The alpha(p) volume fraction was varied between 15 and 70% for a constant alpha(p) grain size of 25 μ. The rate of cooling from the duplex solution temperature was varied between 10 K/s (AC) and 100 K/s (WQ). As the alpha(p) volume fraction increases, yield stress, tensile strength, and creep strength decrease while tensile ductility and HCF performance at $R = -1$ are improved. With an increase in cooling rate from AC to WQ, the improvement of the tensile properties and fatigue behavior increases as the percent content decreases. For fully lamellar microstructures and duplex structures with low percent volume fractions, the creep strength strongly deteriorates as the cooling rate increases from AC to WQ, while no effect of cooling rate is found for duplex structures with high alpha(p) volume fractions. (Author)

A96-41573 Microstructural aspects in elevated temperature fatigue of TIMETAL 1100. C. MUELLER, S. TERTSCH (Darmstadt, Technical Univ., Germany), and L. WAGNER (Cottbus, Technical Univ., Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1280–1287. 11 Refs. Documents available from AIAA Dispatch.

The high-temperature near-alpha titanium alloy TIMETAL 1100 was chosen to study the effect of microstructure in ambient and elevated temperature fatigue. Fully lamellar as well as duplex (alpha-p phase in lamellar matrix) microstructures were produced and the fatigue performance evaluated at a stress ratio of 0.1. In the LCF regime, the fine 13-grain-sized fully lamellar material LF was clearly superior to its coarse-grained counterpart LC with respect to the resistance to fatigue crack nucleation and microcrack growth at ambient temperature. At 600°C, no significant differences in LCF life were found between LC and LF. In the HCF regime, the fatigue strengths at ambient temperature were about the same, while LF was clearly superior to LC at 600°C. The performance of the duplex structures was inferior to both lamellar structures with regard to HCF at ambient and LCF at elevated temperatures. (Author)

A96-41561 HCF-behavior of TIMETAL 1100—Fully lamellar vs. duplex microstructures. J. LINDEMANN, A. BERG, and L. WAGNER (Cottbus, Technical Univ., Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1187–1194. 9 Refs. Documents available from AIAA Dispatch.

Fully lamellar as well as duplex (primary alpha phase in lamellar matrix) microstructures were produced in the high-temperature near-alpha titanium alloy TIMETAL 1100. Annealing (alpha + beta) worked material above the silicide solvus led to the typical coarse prior beta grain sized lamellar microstructures, while fine prior beta grains could be achieved by beta heat treatments below the silicide solvus. For the duplex microstructures, the alpha-p volume fraction was varied between 60 and 20%. The fine grain sized fully lamellar microstructure is superior to its coarse grained counterpart with respect to tensile ductility and LCF and HCF strengths. For the duplex microstructure, both LCF and HCF strengths increase with a decrease in alpha-p volume fraction from 60 to 20%. The HCF results are explained in terms of the resistance to fatigue crack nucleation. (Author)

A96-41560 Creep-fatigue interaction and life behaviour of the titanium alloy IMI 834 at 600°C. T. KORDISCH and H. NOWACK (Duisburg, Univ., Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1179–1186. 8 Refs. Documents available from AIAA Dispatch.

The scope of the present study was to investigate creep-fatigue interaction at 600°C on crack initiation and on crack propagation in the short crack and in the long crack regime. The material had a bimodal microstructure consisting of primary alpha grains at a volume fraction of about 25% in a lamellar matrix of transformed beta-phase. The results showed that creep-fatigue cycles led to a lifetime reduction and to an increase of the propagation rates of short and long cracks. An environmental influence at 600°C was found at long test times, which tended to cause an embrittlement of the surface and therefore had to decrease the mechanical properties. Microstructural investigation showed that at all creep-fatigue interaction tests the transcrystalline crack propagation occurred, and no cavities were formed. Crack initiation occurred in pure LCF and in creep-fatigue tests in the primary alpha grains as well as in the transformed beta matrix.

A96-41559 Optimization of microstructure and mechanical properties of the hot-forged titanium alloy IMI 834 by heat treatment. H. KESTLER, H. MUGHRABI, and H. RENNER (Erlangen-Nuernberg, Univ., Erlangen, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1171–1178. 15 Refs. Documents available from AIAA Dispatch.

The aim of the present work is the characterization and optimization of the mechanical properties of the high-temperature titanium alloy IMI 834 in the as-forged and subsequently heat-treated conditions. Results of creep tests and low cycle fatigue tests indicate that the creep and fatigue properties of forged and heat-treated specimens can be regarded as largely independent of the forging conditions. The effects of aging treatments on the microstructure and the mechanical properties are discussed in terms of microstructural features. (Author)

A96-41558 Influence of cooling rate and beta-grain size on the tensile properties of (a+beta) Ti-alloys. G. KUETJERING, J. ALBRECHT (Hamburg-Harburg, Technical Univ., Hamburg, Germany), and O. M. IVASISHIN (Ukrainian National Academy of Sciences, Inst. of Metal Physics, Kiev, Ukraine), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1163–1170. 6 Refs. Documents available from AIAA Dispatch.

The microstructure of Ti alloys was varied by applying a wide range of different cooling rates after beta-annealing producing lamellar structures with either diffusionally grown or martensitically transformed lamellae. The influence of the differences in the lamellar structure on the tensile properties (yield stress and ductility) was studied. In addition to conventionally processed material, tests were performed on material having a considerably smaller B-grain size produced by rapid heating treatments. (Author)

A96-41544 Microstructure and mechanical properties of the Russian high-temperature alloy BT 25y. G. LUETJERING (Hamburg-Harburg, Technical Univ., Hamburg, Germany), I. LEVIN, V. TETYUKHIN (Vernaya Salda

Metallurgical Production Association, Russia), M. BRUN, and N. ANOSHKIN (All-Russia Inst. of Light Alloys, Moscow, Russia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1050–1057. 5 Refs. Documents available from AIAA Dispatch.

Material from disk forgings of the Russian alloy BT 25y was compared to disk-material of the Ti-6242 alloy. Tensile and fatigue properties at room temperature and 500°C, fracture toughness, and Charpy impact properties at room temperature, as well as creep properties at 500°C, were evaluated. The results indicated that BT 25y exhibited overall better properties than the Ti-6242 alloy. The difference was especially pronounced for fatigue strength and Charpy impact values.

A96-41543 Mechanical properties of the near-alpha titanium alloy TIMETAL 1100 with fine beta-grain size. D. WEINEM, J. KUMPFERT, M. PETERS, and W. A. KAYSSER (DLR, Cologne, Germany), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 2, 1995 (A96-41527 11-26), London, Inst. of Materials, 1996, pp. 1042–1049. 15 Refs. Documents available from AIAA Dispatch.

Tensile properties of the near-alpha titanium alloy TIMETAL 1100 were studied for different microstructures. The existence of a processing window between the beta transus temperature (1010°C) and the silicide solvus temperature (1040°C) makes it possible to produce a lamellar microstructure with relatively small transformed beta grains. Thus microstructure could be varied in a wide range by using three solution heat treatment temperatures, below beta transus, between beta transus and silicide solvus, and above silicide solvus temperature followed by four different cooling rates. The microstructures of the different specimens were studied by optical microscopy. Tensile properties at room temperature and 600°C of TIMETAL 1100 were significantly influenced by the different microstructures resulting from the different thermomechanical treatments. (Author)

United Kingdom Aerospace Literature This month: *Materials Microstructures*

A96-44918 Embrittlement in recrystallised and unrecrystallised Al-Li binary alloys. B. NOBLE, S. J. HARRIS, K. DINSDALE (Nottingham Univ., United Kingdom), and P. D. PITCHER (Defence Research Agency, Farnborough, United Kingdom), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 1317–1322. 7 Refs. Documents available from AIAA Dispatch.

Binary Al-Li alloys containing 2.6 and 3.2 wt% Li were processed to produce, respectively, a recrystallized and an unrecrystallized microstructure. After solution treatment and aging, the alloys were exposed for up to 1000 h at 130°C. The exposure resulted in an increasing strength, reduced ductility, and reduced fracture energy. The causes of the exposure embrittlement are discussed. (Author)

A96-44882 Long term thermal stability of silicide dispersoids in rapidly solidified Al-Fe-V-Si and related alloys. D. M. J. WILKES (Defence Research Agency, Structural Materials Centre, Farnborough, United Kingdom), H. JONES (Sheffield Univ., United Kingdom), and R. W. GAEDINER (Defence Research Agency, Structural Materials Centre, Farnborough, United Kingdom), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 943–948. 28 Refs. Documents available from AIAA Dispatch.

The strengthening silicide phase in 8009 (Al-Fe-V-Si) is shown to be extremely stable even up to 4000 h at 425°C. Measured coarsening rates for this phase and the related alpha-AlMnSi phase are compared with theoretical predictions, and the mechanism and reasons underlying the coarsening resistance are discussed. (Author)

A96-44880 Microstructure and mechanical properties of three dispersion strengthened aluminium base alloys after extended holding at elevated temperatures. R. HAMBLETON, H. JONES, and W. M. RAINFORTH (Sheffield Univ., United Kingdom), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 925–930. 13 Refs. Documents available from AIAA Dispatch.

Three mechanically alloyed Al-base alloys (in wt%: Al-1.8Mg-1.4Li-O, Al-3.4Mg-1.3Li-1.0C-O, and Al-3.4Cu-0.9Mg-0.3Mn + 35% SiC(p)) are shown to retain their microstructures and hardness values after treatments for 10–1000 h at 260–340°C. The origins of this remarkable stability and the different levels of hardness in the three materials are discussed. (Author)

A96-44875 TEM studies of the precipitation in high Zr spray formed Al-Li-Zr. H. R. HABIBI-BAJGUIRANI, J. W. MARTIN, and B. CANTOR (Oxford Univ., United Kingdom), *Materials Science Forum* (ISSN 0255-5476), Vols. 217–222, Pt. 2, 1996, pp. 871–876. 10 Refs. Documents available from AIAA Dispatch.

A spray formed alloy (UL30) was characterized by optical, scanning, and TEM. TEM observation reveals the formation of coherent 20-nm particles of Al_3Zr (beta-prime), after annealing at 365°C for 3 and 6 h, which grow to 40 nm after 100 h annealing. Four-nm precipitates of Al_3Li (delta-prime) were observed throughout the matrix and also surrounding the beta-prime precipitates.

A96-44726 Microstructural development in undercooled and quenched Ni_3Al droplets. H. ASSADI (Cambridge Univ., United Kingdom), M. BARTH (DLR, Inst. fuer Raumsimulation, Cologne, Germany), A. L. GREER (Cambridge, Univ., United Kingdom), and D. M. HERLACH (DLR, Inst. fuer Raumsimulation, Cologne, Germany), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 37–44. 10 Refs. Documents available from AIAA Dispatch.

Rapidly solidified droplets of nickel-rich Ni_3Al were produced by means of EM levitation followed by quenching in liquid Ga-In-Sn. The antiphase domain (APD) patterns have been characterized by TEM, and three distinct regions can be identified within grains of Ni-23.5 at.% Al droplets: an anomalous central region of coarse APDs, the main volume of the grain with fine APDs, and coarse APDs near the grain boundary. Possible explanations for the formation of this particular microstructure are considered and assessed in relation to solidification models and further microstructural observations. (Author)

A96-44724 Influence of melt undercooling on the microstructure of Fe-Ni droplets produced in the Cambridge 6.5 m drop-tube. A. F. NORMAN, F. GAERTNER, and A. L. GREER (Cambridge Univ., United Kingdom), *Materials Science Forum* (ISSN 0255-5476), Vols. 215 and 216, 1996, pp. 21–28. 20 Refs. Documents available from AIAA Dispatch.

Dilute Fe-Ni alloys have been processed by containerless solidification in a drop-tube, and the resulting microstructures have been characterized mainly by optical metallography. For these alloys a competition exists between primary solidification to the equilibrium bcc alpha(Fe) phase and of the metastable fcc gamma(Fe(Ni)) phase. For all droplets with compositions not more than 5 at.% Ni, the primary solidification phase is fcc gamma(Fe(Ni)). With less than 5 at.% Ni the gamma(Fe(Ni)) transforms on solid state cooling to the low temperature bcc alpha(Fe) form giving a Widmanstaetten morphology. With 5 at.% Ni, however, the final microstructure depends on the droplet size. For large droplets (greater than 600 μ) the microstructure transforms to bcc alpha(Fe). In the small droplets (less than 200 μ) the transformation is suppressed, resulting in a retained gamma(Fe(Ni)) microstructure. For 10 at.% Ni, the microstructure consists of the metastable alpha(Fe) phase which is in agreement with the literature. For additions of 30 at.% Ni it is not possible to reach the metastable bcc liquidus so the equilibrium gamma(Fe(Ni)) phase forms from the melt. (Author)

A96-44566 Domain structure-property relations in lead lanthanum zirconate titanate ceramics. M. A. AKBAS, I. M. REANEY, and W. E. LEE (Sheffield Univ., United Kingdom), *Journal of Materials Research* (ISSN 0884-2914), Vol. 11, No. 9, 1996, pp. 2293–2301. 25 Refs. Documents available from AIAA Dispatch.

The domain structure and dielectric properties as a function of lanthanum concentration and Zr/Ti ratio have been investigated in rhombohedral and tetragonal lead lanthanum zirconate titanate (PLZT) ceramics. Transmission electron microscopy revealed that, with increasing lanthanum concentration and Zr/Ti ratio, the long-range-ordered domains (macrodomains) reduced in width, initially being fine scale (20 nm) striations, but eventually forming a 'mottled' contrast (5 nm), characteristic of a relaxor. Relative permittivity measurements as a function of temperature revealed a correlation between broadening of the dielectric maxima and the onset of relaxor-type behavior with the appearance of the striations and mottled (relaxor) contrast, respectively. (Author)

A96-43617 A Moessbauer investigation of phases formed in Al-Fe alloys. S. D. FORDER, J. S. BROOKS (Sheffield Univ., United Kingdom), and P. V. EVANS (Alcan International, Ltd., Banbury, United Kingdom), *Scripta Materialia* (ISSN 1359-6462), Vol. 35, No. 10, 1996, pp. 1167–1173. 13 Refs. Documents available from AIAA Dispatch.

Results of detailed variable temperature Moessbauer studies of $Al_{13}Fe_4$ and Al_6Fe phases in the temperature range 15–300 K are reported. The $Al_{13}Fe_4$ and Al_6Fe phases are found to have Debye temperatures of 419 and 327 K, respectively. The relative amount of each phase can thus be determined, either in extracted phases or in situ in aluminum.

A96-42607 Advances in hard materials production; Proceedings of the 1996 European Conference, Stockholm, Sweden, May 27–29, 1996. Shrewsbury, United Kingdom, European Powder Metallurgy Association, 1996, p. 564 (for individual items see A96-42608–A96-42636).

Papers are presented on recent advances in cutting tool materials, a practical guide to hardmetal manufacturing, a new access to hardmetal parts by injection molding using a polyacetal-based binder system, the development of functionally graded sintered hard materials, grain size control in TiC and ZrC synthesis, the numerical simulation of the compaction and sintering of a cemented carbide, the microwave sintering of hardmetals and ceramics, the macroscopic and microstructural evolution of WC-Co compacts during solid state sintering, a dilatometric study of the sintering process of (TiC-TiN)-NiMo cermets, and the development and applications of nanostructured tungsten carbide/cobalt powders. Papers are also presented on the sintering and mechanical behavior of Si_3N_4-SiC nanocomposites, the influence of shock-wave ultrafine particles on some properties of hardmetal composites, reactions between polycrystalline carbide compacts and liquid Co and Ni binder metals, hard metals and thermodynamic modeling, the microstructure and high-temperature behavior of various cermets and hardmetals, the limited fatigue lives of uncoated and coated hardmetals under cyclic loads, a new approach to the solution of the local stress problem in FGM hardmetals, the elaboration and fracture toughness measurements of Al_2O_3/Al-3% wt Mg cermets with variable metal volume fractions, the mechanical properties and wear behavior of a TiC + TiB_2 composite, and the influence of porosity on transverse rupture strength and fracture toughness of a two-phase alloy. Also presented are papers on the transverse rupture strength, fracture toughness, and hardness of WC-Co composites; the high-temperature internal friction measurements of various TiCN-Mo_2C-Co cermets; the microstructure and cutting performance of diamond-coated cemented carbide; the tribological and microstructural evaluation of biased smooth hot-flame-deposited diamond films; and applications of hard materials.

A96-41827 Microstructural homogeneity improvement in Si_3N_4 by a powder coating method. C. M. WANG (Leeds Univ., United Kingdom), *Journal of Materials Science* (ISSN 0022-2461), Vol. 31, No. 17, 1996, pp. 4709–4718. 47 Refs. Documents available from AIAA Dispatch.

The efficiency of a powder coating technique has been quantitatively evaluated through a comparison of the densification behavior, green compact, and dense material microstructural homogeneity in terms of a 'homogeneity dimension', and mechanical properties, using coated powders and mixed powders in the case of Si_3N_4 powder densified by hot-pressing with the liquid-forming additive system Al_2O_3-TiO_2-SiO_2. For coated powder, a significantly smaller value of the homogeneity dimension was obtained. The oxide phases became redistributed during densification, with the Al-containing phase distributed on a finer scale, and the Ti-containing phase on a coarser scale, compared with the green body. Materials prepared by hot-pressing of coated powders showed a more homogeneous microstructure, higher bend strength and higher Weibull modulus, compared with materials prepared from mixed powders. There were no differences in fracture toughness and hardness between the two types of material.

A96-41816 Joining molybdenum to aluminium by diffusion bonding. R. S. BUSHBY, K. P. HICKS, and V. D. SCOTT (Bath Univ., United Kingdom), *Journal of Materials Science* (ISSN 0022-2461), Vol. 31, No. 17, 1996, pp. 4545–4552. 9 Refs. Documents available from AIAA Dispatch.

The joining of Mo to Al and Al-Cu alloy using diffusion bonding is investigated. Bond strengths were measured by means of a simple shear jig and the joint microstructures characterized by electron microscopy and electron-probe

microanalysis. Successful joints were produced by using a copper foil interlayer to form a eutectic liquid during the bonding process, which helped disrupt the oxide film on Al and promote metal diffusion across the joint interface. When bonding commercial-purity Al to Mo, the Fe present as an impurity caused a ternary eutectic liquid to form and, after solidification of the liquid phase, a thin film of Al_7Cu_2Fe was left behind on the Al. Failure of this joint occurred at a shear stress of 75 MPa, with the fracture path contained within the Al. With superpurity Al, a binary eutectic liquid was produced and the ensuing interface reaction resulted in a multilayered structure of Mo-containing phases. The bond failed at the Mo interface at a stress of 40 MPa. When bonding Al-Cu alloy to Mo without a Cu interlayer, general melting at the interface via eutectic phase formation did not occur, and the interface showed only localized reaction. The joint failed by separation from the Mo. When a Cu interlayer was used, thick regions of multilayered Mo intermetallics formed. Failure of this joint occurred at a stress of 70 MPa, mainly by separation at the Mo interface. (Author)

A96-41725 Tensile properties of a gas atomised Ti_6Al_4V-TiC composite. D. HU, T. P. JOHNSON, and M. H. LORETTO (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2867–2873. 13 Refs. Documents available from AIAA Dispatch.

Room and elevated temperature tensile properties of a gas-atomized Ti_6Al_4V-20 vol% TiC metal matrix composite are presented. The TiC particle size in test pieces varies from 2 to 5.6 μ depending upon the heat treatment conditions. Both the ultimate strength and the 0.2% yield stress of the composite are superior to those of the matrix alloy at temperatures up to 700°C. The increase in the Young's modulus is about 24% over the matrix alloy, and the ductility is decreased to 1–2%. Particle size is found to have a strong effect on the yield stress. The relationship between the yield stress and the interparticle spacing obeys the Hall-Petch relation.

A96-41720 Effects of matrix microstructure and fibre-matrix interactions on the fatigue crack growth response of Ti MMC's. S. V. SWEBY, A. L. DOWSON, and P. BOWEN (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2827–2834. 12 Refs. Documents available from AIAA Dispatch.

The fatigue crack growth response of two continuous SiC fiber (SM 1140+ and SM 1240) reinforced Ti_6Al_4V composites has been studied as a function of prior thermal exposure at temperatures above and below the beta transus and detailed quantitative information has been generated relating to microstructural development and the extent of fiber-matrix interactions. For the SM 1140+ material a progressive improvement in fatigue crack growth performance was observed as the the temperature of exposure was increased toward and beyond the beta transus. In contrast, for the SM 1240 reinforced material a distinct deterioration in crack growth resistance was observed over the same temperature range. These differences in behavior are discussed in terms of the observed microstructural changes in the matrix and the different reaction products formed at the fiber-matrix interface. (Author)

A96-41718 The effect of composition on the elevated temperature mechanical properties of titanium metal matrix composites. M. P. THOMAS, M. R. WINSTONE (High Temperature Materials Behaviour Group, United Kingdom), J. G. ROBERTSON (DRA Sigma, Farnborough, United Kingdom), and B. MORGAN (RAF, Barry, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2811–2818. 12 Refs. Documents available from AIAA Dispatch.

Fabrication trials have resulted in optimized production routes for four Ti MMCs which provide good fiber spacing and no microstructural defects. The tensile strength of the MMCs is similar at 600°C to the unreinforced matrix alloys at room temperature, although the strain to failure is much reduced. Creep lives of IMI834 MMCs at 600°C are an order of magnitude better than IMI318 MMCs in the high stress/short time test regime because of the superior creep properties of the IMI834 monolithic alloy. In the low stress/long time regime the creep advantage of IMI834 MMCs is reduced because of the effect of matrix embrittlement. Best creep properties are exhibited by IMI834/SM1240, which also shows improved low cycle fatigue lives at 600°C.

A96-41701 Microstructural study of titanium-magnesium alloys. C. M. WARD-CLOSE, D. M. J. WILKES, P. S. GOODWIN (Defence Research Agency, Farnborough, United Kingdom), P. G. PARTRIDGE, and K. E. BAGNALL (Bristol Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2673–2680. 3 Refs. Documents available from AIAA Dispatch.

Titanium-magnesium alloys have been produced by the alternative methods of vapor quenching (VQ) and mechanical alloying, and it is demonstrated that both synthesis methods are capable of producing Ti-Mg solid solution alloys. Both hot-pressing of VQ Ti-9Mg at 600°C and vacuum annealing in the TEM at 640°C resulted in extremely fine scale precipitation, identified by electron diffraction and imaging PEELS as being predominantly magnesium. Once precipitated, the particles were found to be remarkably stable. The mechanical alloying route has been demonstrated for a Ti-9Mg alloy and it is shown that full solid solubility can be achieved by careful control of interstitial contamination. (Author)

A96-41700 Titanium based microlaminates by high rate PVD. D. V. DUNFORD, C. M. WARD-CLOSE (Defence Research Agency, Farnborough, United Kingdom), L. COAST-SMITH, R. BRYDSON, and P. TSAKIROPOULOS (Surrey Univ., Guildford, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2665–2672. 11 Refs. Documents available from AIAA Dispatch.

This paper describes recent progress in the development of metallic laminate systems by physical vapor deposition. A brief description of the laminating process is presented. Laminates based on titanium and containing layers of either aluminum, yttrium, or magnesium have been fabricated with accurate layer thicknesses in the range 5 nm to 10 μ and with total laminate thicknesses of about 1.5 min. The development of intermetallic systems from adjacent titanium and aluminum layers by solid state diffusion is reported. Initial studies to determine 1) the suitability of yttrium as a barrier layer and 2) reduced density titanium laminates containing magnesium layers are also presented. (Author)

A96-41697 Spray forming of titanium ring preforms. J. M. YOUNG, M. H. JACOBS, M. DUGGAN, and A. L. DOWSON (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2641–2648. 6 Refs. Documents available from AIAA Dispatch.

A centrifugal spray deposition (CENTRISPRAY) facility capable of operating under near-vacuum conditions and producing near-net shape ring components of up to 400 mm diameter has been developed and demonstrated for both conventional (Ti-6Al-4V) and advanced (Ti-48Al-2Mn-2Nb) titanium-based alloys. Preliminary observations have shown that the process can offer significant advantages over more conventional gas-assisted spray deposition procedures particularly in terms gas entrapment and susceptibility to thermal-induced porosity. In addition, post-spray hot rolling and subsequent XRD and high-temperature mechanical property studies on Ti-6Al-4V alloy shown the process to be an ideal precursor to the production of superplastic sheet material. (Author)

A96-41695 Control of interstitial contamination during mechanical alloying of titanium based materials. P. S. GOODWIN, C. M. WARD-CLOSE (Defence Research Agency, Farnborough, United Kingdom), D. K. MUKHOPADHYAY, C. SURYANARAYANA, and F. H. FROES (Idaho Univ., Moscow), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2626–2633. 16 Refs. Documents available from AIAA Dispatch.

The refined microstructures produced by mechanical alloying offer significant potential in the development of advanced titanium-based materials if the problem of contamination during milling can be addressed. In this paper the various contributory sources of the contamination are reviewed and solutions are discussed. Results are presented from the milling of a Ti-48Al-2W gamma aluminide alloy powder under different atmospheres and the resultant contamination levels examined. Evidence is presented to show that both the fcc phase and the amorphous phase often reported in this type of alloy result from contamination and that their formation is suppressed if milling is performed under clean conditions. (Author)

A96-41676 The nature and role of grain boundaries during grain growth of Ti-6Al-4V in the beta phase field. E. BOSWELL, M. STRANGWOOD, and P. S. BATE (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2446–2453. 8 Refs. Documents available from AIAA Dispatch.

The grain growth associated with heat treatment of Ti-6Al-4V plate in the single-phase beta field has been studied at temperatures of 1015 and 1100°C for times up to 5400 s. The growth rate deviated significantly from the parabolic form, with a relatively decreasing rate at larger grain sizes. Grain orientations, and so boundary misorientations, were determined from traces of Widmanstaetten alpha plates formed on cooling transformation. The preferred crystallographic orientation obtained from those results was consistent with that measured by XRD and became more pronounced with increasing grain size. A general decrease in boundary misorientation and the occurrence of local groupings of similar boundaries was observed, which are likely to be responsible for the slowing down of the growth rate in this alloy. (Author)

A96-41675 The effect of iron modification on the superplastic deformation properties of the titanium alloy IMI550 (Ti-4Mo-4Al-2Sn-0.5Si). M. TUFFS and C. HAMMOND (Leeds Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2438–2445. 13 Refs. Documents available from AIAA Dispatch.

The superplastic deformation properties of the two-phase alloy Ti-4Mo-4Al-2Sn-0.5Si (IMI550) which was modified by the replacement of 1% Mo with 1% Fe were assessed at 800 and 850°C. Alloy modification resulted in reductions in flow stress of more than 20% throughout the superplastic range and slightly higher maximum strain rate sensitivities at both temperatures. The inhomogeneous grain structure in the as-received material, consisting of coarse and fine alpha and beta grains, was homogenized as a result of deformation, i.e.

a fine equiaxed grain structure was evolved. The beta phase also existed as a thin film separating some alpha grains. The stress-strain rate curves obtained experimentally for the base and modified alloys have been compared to those predicted using the Ashby and Verrall (1973) model in which superplastic flow is accommodated by diffusional flow. The relative contributions to the deformation of the alpha and beta phases were combined using both the isostress and isostrain rate models. It was found that the reductions in flow stress achieved by the addition of iron could not be fully accounted for by the isostrain rate model and that the isostress model was more closely followed whereby the overall superplastic properties are biased toward the softer beta phase. (Author)

A96-41659 The development and evaluation of beta titanium alloys for aerospace applications. Y. G. LI, X. D. ZHANG, P. A. BLENKINSOP (Birmingham Univ., United Kingdom), N. SAUNDERS (Birmingham Univ.; Thermotech, Ltd., Guildford, United Kingdom), N. A. WALKER, P. D. SPILLING, and C. SMALL (Rolls-Royce, PLC, Derby, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2317–2324. 7 Refs. Documents available from AIAA Dispatch.

Highly alloyed beta titanium alloys have been investigated in view of their potential as high temperature and high strength meterials. The program of work reported in the paper is based on alloys derived from a Ti-V-Cr-Al system which have been prepared using plasma cold hearth melting. With the assistance of computer phase modelling, an extensive range of compositions has been melted for evaluation. Data are presented on the composition, processing, microstructure, and phase relationships for a range of highly stabilized beta alloys. (Author)

A96-41652 An electron back-scattered diffraction study of the annealing behaviour of cold rolled titanium. H. S. UBHI and A. W. BOWEN (Defence Research Agency, Farnborough, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2265–2272. 10 Refs. Documents available from AIAA Dispatch.

The orientations of new grains that evolve during the annealing of cold-rolled commercial purity titanium were studied by exploiting the ability of the electron-backscattered diffraction pattern (EBSD) technique to determine local grain orientations. Changes in hardness and XRD pole figure measurements and line broadening analyses were also used as complementary tools. Laboratory annealing experiments were conducted between 520 and 620°C for up to 1 h. EBSD and X-ray pole figures showed little change due to annealing except for a reduction in the smoothness of the intensity contours in the latter case. EBSD data from individual grains provides strong evidence that the substructure in the deformed grains accumulate preferential misorientations of up to 40 deg. These misorientations occurred about the rolling, transverse, and normal directions. As the substructure anneals out during heat treatment, this orientation spread is reduced but the rate of recovery is inhomogeneous. Strain-free grains evolve by a process of recovery with no new orientations forming. The deformation twins are consumed by the surrounding matrix and have no influence on the annealing behavior. (Author)

A96-41649 The effect of oxygen on microstructure of alpha and alpha2 phase in titanium-rich Ti-Al alloys. M. G. ARDAKANI, B. A. SHOLLOCK, and H. M. FLOWER (Imperial College of Science, Technology, and Medicine, London, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2242–2249. 16 Refs. Documents available from AIAA Dispatch.

Titanium-rich 6, 7, 9, and 11 wt% Al alloys containing approximately 700 and 3000 ppm oxygen were ice-water quenched from the beta phase field. It was found that the beta phase transforms to the alpha phase on quenching, having featureless and lath structures in alloys with low and high oxygen content respectively. The nucleation of the alpha2 phase was found to be homogeneous in alloys with low O_2 heat-treated below 800°C, whereas heterogeneous nucleation at the lath boundaries and at dislocations was observed in high O_2 containing alloys heat-treated above 700°C. The morphology of the Ti_3Al phase was found to be elongated along 0001-line and this was accentuated in alloys with low oxygen contents, whereas the shape and size transverse to 0001-line were similar in both low and high oxygen containing alloys. The position of the alpha/alpha + alpha2 phase boundary in alloys containing 3000 ppm oxygen was found to shifted to higher temperatures and lower Al content. (Author)

A96-41647 Phase equilibria and transformations in the Ti-Zr-Si system. N. H. SALPADORU and H. M. FLOWER (Imperial College of Science, Technology, and Medicine, London, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2220–2227. 14 Refs. Documents available from AIAA Dispatch.

The phase equilibria and transformations in the titanium-zirconium rich region of the ternary Ti-Zr-Si system were studied in the temperature range 1473–1073 K together with microstructures present in the as-cast state. DTA, microscopy, XRD, and chemical analysis by X-ray EDS were employed. Isothermal sections of the Ti-Zr-Si system are presented for 1073 K and related to these at higher temperatures reported previously. The effect of oxygen on phase equilibria involving certain zirconium-rich binary and ternary equilibrium phases was also determined. The system contains a ternary silicide identifiable with that first observed by Flower et al. (1971) and subsequently reported and denoted S_2 in a range of commercial titanium alloys. The silicide has the general formula $(Ti, Zr)_2Si$ with a Ti:Zr ratio ranging from 2.26 to 0.68. The variation in lattice parameters, microhardness, and density of this phase with Ti:Zr ratio is also presented. (Author)

A96-41645 Alloy development; titanium. D. F. NEAL (IMI Titanium, Ltd., Birmingham, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2195–2204. Documents available from AIAA Dispatch.

The historical perspective, fundamental principles, and driving forces for titanium alloy development are reviewed. These factors are used to illustrate the progress achieved in around 50 years of titanium alloy development. The perspective is broad: not only how alloy compositions are formulated but also how other considerations such as fabrication, microstructure, and, more recently, cost impinges on this. Despite the large number of available alloys, new developments have continued to appear, and these are discussed in more detail. (Author)

A96-41637 Oxidation behaviour of highly beta stabilised titanium alloys. X. D. ZHANG, P. A. BLENKINSOP (Birmingham Univ., United Kingdom), and N. A. WALKER (Rolls-Royce, PLC, Derby, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2111–2118. 5 Refs. Documents available from AIAA Dispatch.

Highly stabilized beta titanium alloys containing Mo, such as Beta 21S, have been shown to have good oxidation resistance. In the present investigation a series of alloys based on the Ti-V-Cr system has been studied and their oxidation performance determined by weight gain measurements and microstructural assessment over a range of temperatures. The data presented will cover not only performance of the alloy at their likely processing temperatures, but also include temperatures relevant to their potential range of application. The paper discusses the oxidation mechanism for the alloys and makes comparisons with commercial high-temperature titanium alloys and titanium aluminides. Data are presented on the long-term stability of the alloys and the associated microstructural changes. (Author)

A96-41634 High temperature plasma immersion ion implantation of Ti_6Al_4V alloy. S. JOHNS, T. BELL (Birmingham Univ., United Kingdom), G. COLLINS, K. T. SHORT, and J. TENDYS (Australian Nuclear Science and Technology Organisation, Lucas Heights, Australia), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2081–2088. 8 Refs. Documents available from AIAA Dispatch.

The plasma immersion ion implantation (PI3) process has been applied to the surface of Ti_6Al_4V alloy in order to effect some improvement in its tribological properties. This surface modification technique has been developed recently at the Australian Nuclear Science and Technology Organisation (ANSTO), and is essentially a 'hybrid' of the ion implantation and plasma nitriding processes. Ti_6Al_4V samples were treated at 550°C in a pure nitrogen atmosphere, with high voltage pulses applied directly to the workpiece. Wear resistance of the treated samples was assessed using a standard CSEM pin-on-disk wear machine, with a single crystal ruby ball as the contact tip. Glancing angle X-ray diffraction (GAXRD) was employed to determine the structural changes in the surface layer. It was observed that the contributions of TiN and Ti_2N developed in the surfaces of the alloy varied significantly between samples. Optimum wear resistance was achieved in specimens which exhibited substantial contributions from both phases. It is proposed that these microstructural differences may be attributable to variations in the nitrogen dose rate during PI3 treatment. (Author)

A96-41633 Electron beam surface alloying of Ti_6Al_4V for resistance to contact loading. A. BLOYCE, H.-M. W. HAILU, and P. H. MORTON (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2073–2080. 6 Refs. Documents available from AIAA Dispatch.

It is shown that electron-beam surface alloying of Ti_6Al_4V with preplaced Si + C powders can be accomplished in a controlled and reproducible manner. A relatively hard surface-alloyed volume can be created free of cracks, porosity, and any significant chemical and microstructural inhomogeneity. The major phases of the resultant microstructures are TiC, primary alpha/alpha-prime-Ti, eutectic alpha/alpha-prime-Ti, and Ti_5Si_3. Microhardness tests, pin-on-disk wear tests, and Amsler sliding-rolling tests indicate the potential for this surface-alloyed material in gear applications.

A96-41628 The development of wear resistant surfaces on CPTi and Ti-6Al-4V alloys by laser nitriding. H. XIN and T. N. BAKER (Strathclyde Univ., Glasgow, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2031–2038. 9 Refs. Documents available from AIAA Dispatch.

Laser nitriding of commercially pure titanium and Ti-6Al-4V alloy surfaces under several nitrogen concentrations has been carried out. The volume and hardness of TiN formed was dependent on the surface to volume ratio of the melt pool, the interaction time, and the concentration of the reactive gas. XRD analyses have led to the conclusion that the resolidified zone of the nitrided specimens consisted of TiN, TiN(0.3) and martensitic alpha-Ti. The abrasive

wear behavior of the titanium nitride surface was followed using a pin-on-disk machine. SEM has shown that the basic wear mechanism is primarily ploughing, which was studied by examining the worn surfaces and wear debris. The abrasive wear rate of 100% nitrided CPTi was nearly two orders of magnitude lower than that of the untreated alloy, while the corresponding figure for Ti-6Al-4V alloy was about two. (Author)

A96-41625 New surface hardenable wear resistant titanium alloy development. H. DONG, A. BLOYCE, P. H. MORTON, and T. BELL (Birmingham Univ., United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 2007–2014. 9 Refs. Documents available from AIAA Dispatch.

To explore the feasibility of producing a new surface-hardenable titanium alloy, four Ti-Si binary alloys containing 7, 8.5, 12, and 15 wt% silicon, respectively, were melted and examined. Metallographic examination revealed that the microstructure of Ti-(8.5)Si was very fine, but that of Ti-12Si and Ti-15Si contained coarse proeutectic dendrites of Ti_5Si_3 in the matrix of the eutectic. All the new alloys, except for Ti_7Si alloy, can be effectively hardened by EB surface melting. Both microstructural refinement hardening and solid solution hardening account for the hardening effect. Taking into account both the hardening effect of the surface melted layer and the structure of the bulk materials, the preferred composition is Ti-(8.5)Si. Experimental results also revealed that duplex treatments, involving EB surface melting followed by plasma nitriding of the new Ti-(8.5)Si alloy, has produced a system with promising wear resistance and load-bearing capacity. Moreover, Ti-(8.5)Si also shows high abrasive wear resistance when the surface is hardened by EB. (Author)

A96-41620 Hardness, dendrite population and microstructure under different nitrogen environments in the laser nitrided Ti-6Al-4V alloy. C. HU, S. MRIDHA, T. N. BAKER (Strathclyde Univ., Glasgow, United Kingdom), H. S. UBHI, P. HOLDWAY, and A. W. BOWEN (Defence Research Agency, Farnborough, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 1959–1966. 15 Refs. Documents available from AIAA Dispatch.

Laser nitriding of the Ti-6Al-4V alloy in a pure nitrogen environment produced high-hardness tracks (about 1500 Hv) which contained cracks on the surface and in the vertical sections. It was possible to avoid cracks after nitriding in a dilute nitrogen environment, but at the expense of the hardness, which was reduced to about 1000 Hv. The hardness was found to be associated with the concentration of dendrites in the melt pool, and it was higher in tracks produced in those dilute environments containing a greater nitrogen concentration in the gas mixture. This paper describes the dendrite populations, hardness profiles, and microstructural features of the nitrided tracks, developed in laser-nitrided material with different nitrogen concentrations in the environment with the aim of optimizing the laser processing conditions to give a high-hardness crack-free surface. (Author)

A96-41619 The influence of alloy composition on the formation of nitride on titanium alloys heated in air. D. F. NEAL and P. S. GARRATT (IMI Titanium, Ltd., Birmingham, United Kingdom), *Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium*, Birmingham, United Kingdom, Vol. 3, 1995 (A96-41613 11-26), London, Inst. of Materials, 1996, pp. 1951–1958. Documents available from AIAA Dispatch.

The scales formed on a range of alloys after high temperature exposure in air have been investigated. It has been discovered that, contrary to previous experience, nitride scale can form readily on many of the most widely used titanium alloys. The alloy composition, or more specifically the presence of a particular alloying element, appears to be the significant factor. The paper will present data on the effect of alloy composition on the type and rate of scale formation and discuss the ramifications with respect to fabrication and recycling. (Author)

A96-41613 Titanium '95—Science and technology; Proceedings of the 8th World Conference on Titanium, Birmingham, United Kingdom, Vol. 3, Oct. 1995. P. A. BLENKINSOP (Birmingham Univ., United Kingdom), W. J. EVANS (Univ. of Wales, Swansea, United Kingdom), and H. M. FLOWER (Imperial College of Science, Technology, and Medicine, London, United Kingdom) (eds.), London, Inst. of Materials, 1996, p. 1036 (for individual items see A96-41614–A96-41708, A96-41710–A96-41727).

Various papers on titanium are presented. The general topics addressed include: intermetallics; forging, casting, mechanical forming, joining, and modelling; mechanical properties and microstructures; raw materials, primary processing, melting, modelling, recycling, and inspection; aerospace and nonaerospace applications; environmental behavior and surfaces; alloy development, alloy constitution, and structure; powder and spray forming; vapor deposition; and metal matrix composites.