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Work Order Directive (WUD) 49

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THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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14. ABSTRACT
A wide range of research related to the deformation, solidification, and vapor processing of materials of importance to the Air Force was conducted under this Work Unit Directive. The primary theme of all of the research was to establish the physics of materials behavior during processing and to exploit this knowledge to improve existing processes and develop new processes. The important results are discussed in the following sections on intermetallic alloys, conventional alloys, advanced modeling tools, composite materials/thermal barrier coatings, and novel processes.

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FINAL REPORT: WUD 49 – Metals Processing/Processing Science

RESEARCH OBJECTIVES

- To establish scientific methods to describe, design, and control fabrication processes for the purpose of producing high integrity, complex shape components for advanced aircraft and space systems.
- To develop a fundamental understanding of the constitutive, phase transformation, and texture evolution behavior of metallic and emerging intermetallic alloy systems to produce materials with novel microstructures and textures.
- To develop advanced modeling techniques for predicting microstructure and texture.
- To extend the processing science methodology to the fabrication of advanced composite, graded, and multifunctional materials.

SUMMARY OF IMPORTANT RESULTS

A wide range of research related to the deformation, solidification, and vapor processing of materials of importance to the Air Force was conducted under this Work Unit Directive. The primary theme of all of the research was to establish the physics of material behavior during processing and to exploit this knowledge to improve existing processes and develop new processes. The important results are discussed in the following sections on intermetallic alloys, conventional alloys, advanced modeling tools, composite materials/thermal barrier coatings, and novel processes.

Intermetallic Alloys

Research on intermetallic alloys focussed on the mechanisms controlling microstructure evolution and defect formation during the processing of ingot-metallurgy gamma titanium aluminides. This research concerned various aspects of ingot production, primary breakdown, secondary processing, and final heat treatment.

Ingot Production. Research on ingot production dealt with the formulation of models for the development of thermal stresses and thermal cracking during ingot casting and reheating and obtaining an understanding of segregation/homogenization phenomena in gamma titanium aluminide alloys. The development of thermal stresses during the vacuum arc remelting (VAR) and permanent mold casting (PMC) of ingots was modeled via numerical solution of the two-dimensional, nonsteady-state heat conduction and stress equilibrium equations. The predicted development of large tensile stresses correlated well with observations of thermal cracking during VAR of near-gamma titanium aluminide alloy ingots. By contrast, the predicted thermal stresses developed during PMC were lower, thus suggesting an attractive alternative to VAR to obtain sound, crack-free ingots. The development of temperature gradients and thermal stresses during the *reheating* of large ingots was also investigated with special reference to the selection of heating schedules for brittle intermetallic materials such as the titanium aluminides. Comparison of the predicted thermal stresses and actual ingot heating observations suggested that cracking is controlled by a maximum *normal* stress criterion. In the area of ingot structure, observed micro-segregation was explained in terms of the double-cascading peritectic reactions which characterize the Ti-Al phase equilibria. Homogenization heat treatments were developed to eliminate such segregation. An interface-reaction-controlled mechanism was deduced to control the homogenization kinetics.

Primary Hot Working. The underlying mechanisms that control constitutive response, microstructure evolution, and fracture during primary hot working of gamma titanium aluminide alloys were determined. Using samples with lamellar microstructures and various alpha grain sizes, it was determined that the deformation/constitutive bahavior during primary (breakdown) hot working of gamma titanium aluminide alloys is controlled by a mixed mode of plastic flow (viz., matrix-dislocation *and* grain-boundary-deformation processes) even at high strain rates. Such deformation mechanisms also explain the marked grain-size dependence of globularization kinetics for TiAl alloys. In the area of fracture modeling, a modified Griffith-Stroh criterion was applied for the prediction of wedge crack formation during bulk forming of TiAl alloys. It was found that wedge cracking occurred in various alloys at a critical value of the product of the applied stress and the square root of the grain/colony size. However, the specific values of this product were different for cast versus wrought TiAl alloys. The fracture results also revealed transitions from brittle behavior (in which wedge cracks grew and led to catastrophic failure at very low strains) to ductile behavior (in which microvoid initiation and growth was gradual) over rather narrow temperature ranges; the brittle-to-ductile transition temperature increased with increasing strain rate. Furthermore, the transition temperatures for a given strain rate were higher for coarse-grained material than for finer-grained, wrought material. An Arrhenius-type analysis of the transition-temperature data yielded values of activation energy comparable to those that describe the dynamic recrystallization of gamma titanium aluminide alloys during hot compression testing. A detailed metallographic investigation verified that the onset of dynamic recrystallization was indeed the mechanism by which brittle fracture was suppressed.

The fundamental understanding of material behavior was utilized in the development of process models for isothermal forging, conventional (canned) hot forging, conventional (canned) hot extrusion, and pack rolling of gamma titanium aluminide alloys. Integration of the material behavior and process models enabled the design of processes to obtain a wide range of microstructures in gamma titanium aluminide alloys. For example, pack rolling or pack rolling followed immediately by short-time heat treatment was utilized to produce microstructures ranging from very fine equiaxed gamma + alpha - two (with excellent superplasticity properties) to refined fully lamellar gamma + alpha - two (with an excellent combination of ductility, toughness, and creep properties).

Secondary Hot Working. Research on secondary processing of intermetallic alloys focused on obtaining an understanding of the failure mechanisms and plastic flow phenomenology during the nominally superplastic deformation of titanium aluminide materials. For this purpose, a method for incorporating the effects of cavitation and plastic anisotropy into a simple, equilibrium-type, analysis of the uniaxial sheet tension test was developed. Model results delineated the competition between failure-controlled by localized necking vs fracture, the latter being defined by a critical-volume fraction of cavities. The validity of the modeling approach was confirmed through the analysis of data in the literature as well as our own observations for the wrought near-gamma titanium aluminide alloy Ti-45.5Al-2Cr-2Nb and the wrought orthorhombic titanium aluminide alloy Ti-21Al-22Nb (atomic percent). The ductility of the gamma titanium aluminide alloy was controlled by cavitation rather than by flow localization. In these materials, the majority of cavities were initiated at boundaries between gamma and alpha-two grains. The initiation was ascribed to the difficulty of strain accommodation in the hard-to-deform alpha-two phase.

Final Heat Treatment. A fundamental understanding of phase equilibria, alpha grain growth at temperatures high in the two phase (alpha + gamma) field or single-phase alpha field, and the kinetics of alpha phase decomposition to control the lamellar, massive, etc. transformation behavior was obtained. Alpha-grain growth behavior in the presence of a stable or dissolving second phase was established. At subtransus temperatures (in the two-phase field), the growth of alpha grains in the presence of a gamma-particle dispersion was found to follow a trend that could be predicted based on the grain-growth kinetics of single-phase alpha and the retarding force of the second-phase particles. A grain growth exponent of 2.6 was found to describe the subtransus behavior. Short-time grain growth behavior at supertransus temperatures (in the single phase alpha field) was interpreted in terms of the kinetics of gamma particle solutioning and the long-time grain growth of single-phase alpha grains. The gamma particle dissolution kinetics were deduced to be diffusion controlled, a finding that contrasted with previous observations of interface-reaction controlled kinetics for the homogenization of gamma titanium aluminides containing bands of gamma grains. This difference in behavior was hypothesized to be a result of differences in the nature of the alpha-gamma interfaces in the two cases. The gamma particle dissolution and alpha grain growth models were integrated with a simple heat transfer analysis to design a heat treatment process to produce a moderate alpha grain size, fully lamellar microstructure in both subscale and full scale forgings.

Conventional Alloys

Research on conventional alloys focussed on thermomechanical processing (TMP) of both nickel-base and titanium alloys and solidification processing of titanium alloys.

TMP of Nickel-Base Superalloys. The objective of work on the processing of nickel-base superalloys was to develop material behavior models to describe and control microstructure evolution during hot working processes such as isothermal and nonisothermal forging. Microstructure evolution during hot working of *wrought* Waspaloy and Incoloy 901 was investigated in the context of previous phenomenological models formulated for steels. For Waspaloy, the kinetics of dynamic recrystallization (DRX), metadynamic recrystallization, and grain growth were established. The microstructure evolution models were combined with finite element method (FEM) modeling to predict microstructure development in isothermal and hammer forgings. The phenomenological results were also used to validate the mesoscale (cellular automata) mechanism-base models of recrystallization described in the next section. Work was also begun to establish models for plastic flow and microstructure evolutiion during the breakdown of *cast-and-homogenized* Waspaloy ingot material. Initial results indicated the important effects of crystallographic texture and grain-subdivision processes on constitutive behavior and the nucleation-and-growth processes that control recrystallization behavior.

TMP of Titanium Alloys. Extensive work was conducted to establish the mechanisms that control plastic flow, microstructure/texture evolution, and defect formation during the breakdown of colony microstructures in alpha/beta titanium alloys such as Ti-6Al-4V.

The hot deformation of the alpha/beta titanium material was found to be controlled by the glide and climb of dislocations. Globularization of the lamellar microstructure occurs at large strains after noticeable texture changes have occurred. The mechanisms of globularization were deduced to a combination of platelet shearing, boundary splitting, and termination migration/coarsening. Using orientation imaging microscopy (OIM), it was also found that slip transmission across these interfaces appears to play a key role in globularization behavior and the local crystallographic rotations that control the development of the texture of the globularized phases. Furthermore, OIM was used successfully to reveal the local texture changes associated with deformation nonuniformities within a given colony.

With respect to the influence of texture on plastic flow, the peak flow stress and plastic anisotropy parameters ('r values') of compression samples cut from a highly - textured plate showed a significant anisotropy with respect to test direction over a wide range of hot working temperatures. These trends were explained semi-quantitatively using crystal plasticity calculations based on a Taylor approach (LApp model). However, the crystal plasticity calculations suggested that texture changes during deformation should give rise to flow *hardening*, not flow *softening* as observed. Hence, a microstructural source for the observed flow softening was sought. To this end, the values of the Hall-Petch strengthening associated with dislocation pileups at alpha/beta interfaces were deduced from flow stress data for colony and equiaxed materials with identical textures. The magnitude of this dependence was predicted by the classical Eshelby expression for grain-size strengthening. The magnitude of such interface strengths also correlated well with the measured values of the overall level of flow softening. In addition, the elimination of the second-order effect of texture hardening enabled the derivation of the purely microstructural contribution to flow softening and the definition of an important internal state variable to describe constitutive behavior. This seminal discovery of the source of flow softening was used to explain one of the key mechanisms of dynamic globularization and microtexture evolution (i.e., platelet shearing) during ingot breakdown.

The source of "strain-induced-porosity" (SIP) in large alpha/beta titanium alloy forgings was also established. Such porosity occurs as wedge cracks/cavities that are believed to be developed during the initial subtransus forging passes after beta working or annealing and can lead to substantial losses in mechanical properties. Using uniaxial tension tests, the workability in terms of void initiation/growth kinetics and overall ductility were determined as a function of microstructural features such as the beta grain size, grain boundary alpha layer thickness, etc. With these material behavior data, the occurrence of SIP in simulative nonisothermal upset and sidepressing tests was established. Using FEM models of these processes, an appropriate damage initiation/fracture criterion for SIP and edge cracking was formulated. Specifically, the continuum approaches developed by Cockcroft and Latham (tensile-work criterion) and by Rice and Tracey (void-growth model) were successfully applied to predict the *initiation* of microscopically observable cavities as well as gross fracture under the influence of the complex stress state that characterizes forging.

Solidification Processing of Titanium. In the area of solidification processing of titanium, a novel technique was developed to measure the temperature transients that occur during permanent mold casting, a low cost alternative to investment casting. Such measurements are critical to the validation of solidification models and hence the interpretation and prediction of microstructure in the casting process. Using this technique, the development of equiaxed versus columnar grain structures during permanent mold casting and vacuum arc remelting was rationalized on the basis of the specific solidification rates and temperature gradients that occur during such operations. In particular, the columnar-to-equiaxed transition was quantified as a function of temperature gradient and solidification rate. The transition was explained using the classical Hunt criterion using reasonable values for the input parameters. In addition, the fundamental understanding of microstructure evolution during *macro*-casting processes was extended to explain the occurrence of columnar grain structures developed during the micro-casting of alpha/beta titanium alloys via solid freeform fabrication/laser deposition

The mechanisms of texture evolution during laser deposition of Ti-6Al-4V, a low-cost alternative to conventional ingot-metallurgy processing, were elucidated with the aid of orientation-imaging microscopy. These efforts revealed that epitaxial growth from the substrate (beta) texture and rapid growth of (100)-oriented beta grains compete in the determination of the deposit texture.

Advanced Modeling Techniques

Significant research was made in the development and/or application of advanced models for quantifying microstructure, texture, and cavitation during processing. Some of the research highlights in this area are described in the following subsections.

Cellular Automata. A cellular automaton approach to determine the spatial and temporal evolution of structure during phase transformations controlled by nucleation and growth was formulated. In particular, the kinetics of homogeneous and heterogeneous static recrystallization in a single-phase material were analyzed using 2D cellular automata (CA). The CA algorithm was verified using JMAK (Johnson, Mehl, Avrami, Kolmogorov) theory for homogeneous site-saturation and constant rate nucleation. The algorithm was then modified for heterogeneous nucleation at grain boundaries with either a fixed number of nuclei or a constant rate nucleation. The fraction of boundary sites with nuclei was varied from 0.006 to 0.28 resulting in Avrami exponents (k) ranging from 1.8 to 1.1 for site-saturation conditions. The parameters q and m from Vandermeer's microstructural path method were calculated, and compared well with theoretical values. Constant-rate nucleation at boundaries other than those of the parent material resulted in k's of ≈ 1. With a low nucleation rate, recrystallized grains formed in clusters, while a high nucleation rate resulted in a necklace microstructure with kinetics similar to those observed in dynamic recrystallization of nickel-base superalloys (k=1.41).

An in-depth investigation of dynamic recrystallization (DRX) using the CA method was also conducted with good success. Predictions of flow curves and microstructures developed during DRX showed excellent agreement with observations.

Cellular automata modeling of recrystallization processes during the hot-working of coarse columnar-grain superalloy ingot structures and the solidification of titanium alloys was also begun.

Crystal Plasticity FEM. Research to develop a crystal plasticity FEM (CPFEM) method to predict deformation textures for alpha/beta titanium alloys with colony alpha microstructures, taking into account the presence of 'hard' and 'soft' slip systems due to the presence of lamellar interfaces, was begun. For this purpose, initial direct measurements of the relative strengths of basal <a>, prism <a>, and pyramidal <c+a> slip systems were conducted using single colony samples of Ti-6Al-4V grown by a directional solidification technique. A CPFEM code developed at Cornell University was exercised with these preliminary data.

Phase-Field Modeling. Research on phase field modeling of precipitation processes in nickel-base superalloys under isothermal conditions was completed under the current work unit directive. Efforts were also begun to develop a phase-field analysis of the precipitation of gamma prime during the nonisothermal heat treatment of superalloys.

Cavitation Models. Substantial work comprising mesoscale and microscale modeling of cavitation was conducted to complement the phenomenological work on strain-induced porosity in titanium alloys and cavitation during superplastic forming of gamma titanium aluminide alloys. In the mesoscale efforts, the effects of continuous cavity nucleation, cavity growth, and cavity coalescence on ductile fracture during hot working were established. For example, the models were successful in demonstrating those microscopic processes which control the macroscopic (apparent) cavity initiation strain and cavity growth rate as well as the average cavity size and cavity-size distribution. Using a microscale modeling approach based on a constrained-plasticity analysis, early-stage cavity growth at grain-boundary defects was quantified. The importance of the size of the 'defect' at which the nanocavity is initiated (e.g., second-phase particle, lamellar plate thickness) and material properties such as the strain-rate sensitivity in controlling early-stage growth was quantified.

MMCs/TBCs

Research on the processing of composites and coatings focussed on advanced models for the consolidation of porous media and processing-structure-property relations for thermal barrier coatings.

MMC Consolidation from Tapecast Monotapes. Research on the hot consolidation of continuous-fiber MMCs from tapecast monotapes focussed on the development of a material behavior model for porous media. A hybrid approach making use of the best features of continuum and micromechanical descriptions of the yielding and flow of powder compacts was taken. To this end, a continuum yield function and associated flow rule modified to incorporate microstructure effects such as grain growth, pore size, and pore geometry were developed. It was demonstrated that the consolidation behavior of a variety of *monolithic* powder metals (and ceramics) could be described over a large range of densities by the determination of two parameters in the yield function/flow rule, i.e., the stress intensification factor and Poisson's ratio. Both parameters are functions of relative density, whose exact dependence varies from one material to another. Methods of measuring the values of these parameters using uniaxial hot compression and microhardness testing were derived. The application of hot compression testing to establish the effects of pore anisotropy (that may develop during simple or complex loading paths) on yielding behavior were also determined.

The hybrid continuum-micromechanical yield function/flow rule for powder metals was utilized in both numerical (FEM) and analytical models of the hot consolidation of layups of tapecast monotapes. The relative matrix density-versus-time profiles predicted from the analytical approach showed very good agreement with average density predictions from the detailed FEM calculations as well as experimental observations for the HIP consolidation of monotape layups.

TBCs. The temperature dependence of the thermal conductivity of multi-layer coatings made by plasma spray and physical vapor deposition (PVD) techniques was established as part of an effort to determine processing-microstructure-property relations for ceramics used as thermal barrier coatings in turbine engine applications. The multi-layer coatings consisted of a varying number of layers of alumina and yttria stabilized zirconia. The majority of the reduction noted in the thermal conductivity of the plasma spray coatings was due to the presence of porosity. The reduction seen in the PVD coatings could be explained by the rule-of-mixtures using the proper phase proportions of the zirconia (i.e. monoclinic versus tetragonal). The *absence* of a measurable effect of layering on conductivity was rationalized based on the fact that the mean free path for phonon scattering is less than the layer thickness that can be readily achieved by the processes investigated.

NOVEL PROCESSES

Using the basic research discoveries under other subtasks of this program, a number of novel deformation, composite-consolidation, and heat-treatment processes were developed.

Novel Deformation Processes. Several deformation processes were been developed to improve the ability to control microstructure and improve product yield for intermetallic alloys (such as the gamma titanium aluminides) and other difficult-to-work metals. These comprise the controlled dwell extrusion technique, the so-called "smart forging" method, and the upset ECAE technique. The first of these processes pertains to canned extrusion and specifically to the design of cans/insulation layers and the selection of the transfer time in air after removing a canned billet from the furnace prior to extrusion. Judicious choice of these variables permits the development of a temperature difference between the can and billet prior to extrusion. For can materials which tend to be considerably softer than intermetallic billet materials, such a temperature difference may make the flow stresses during extrusion more nearly equal and thus improve the ability to coextrude the billet and can more uniformly. The "smart forging" process is a technique to refine grain structure during isothermal breakdown forging. It involves increases in deformation rate as the workpiece recrystallizes and becomes more workable. The upset ECAE technique is a modification of the equal channel angular extrusion process developed originally in the former Soviet Union. The application of conventional ECAE to aerospace alloys which exhibit a large degree of flow softening during hot working usually leads to grossly nonuniform flow. A modified technique was developed in which the workpiece is subjected to an initial increment of upset deformation prior to the simple shear that is imposed in the ECAE deformation zone. Because the tendency for flow softening and thus shear localization is generally greatest at small strains, the initial increment of upset deformation can be used to avoid the nonuniform flow that would otherwise develop.

Rapid Consolidation of Metal-Matrix Composites (MMCs). The feasibility of the rapid consolidation of foil-fiber-foil composites using a hot forging approach was established as an alternative to slower and more expensive processes such as those based on hot isostatic pressing (HIP) or vacuum hot pressing (VHP). A firm basis for the technique was developed through theoretical analyses of temperature transients, forging pressures, and fiber fracture. These analyses demonstrated that there exists an optimal forging speed at which the consolidation stresses are a minimum. It was also shown that the flow stress of the encapsulation material relative to that of the densifying layup is an important consideration in achieving full consolidation during forging. Specifically, the difference in flow stress between the two materials influences the magnitude and sign of the in-plane (secondary) stresses that are developed during forging and therefore the rate of pore closure during the latter stages of the process. With regard to fiber fracture, analyses were performed to estimate the axial and tangential stresses during rapid consolidation. The theoretical work was validated by experimental trials using the Ti-24Al-11Nb matrix/silicon carbide fiber system. Measured forging pressures were in good agreement with predictions. Fiber fracture observations indicated that tangential tensile stresses developed in the fiber control failure; a forging window to avoid such failures was thus developed. Finally, it was demonstrated that matrix microstructures and mechanical properties similar to those of conventionally consolidated Ti-24Al-11Nb/silicon carbide composites can be achieved by the forge-consolidation technique.

Rapid Heat Treatment Processes. The feasibility of using rapid heating methods for producing graded microstructures, for recrystallization annealing, etc., of titanium, titanium aluminide, and other nonferrous alloys was established. For example, the kinetics of beta or alpha grain growth during short-time, isothermal or continuous, supertransus heat treatment of conventional alpha-beta titanium alloys and gamma titanium aluminide alloys, respectively, were determined and shown to be related to descriptions for long time isothermal heat treatments. These kinetics descriptions, in conjunction with standard equations for induction heating, were used to design rapid heating techniques for producing a graded (equiaxed alpha/Widmanstatten alpha) microstructure and hence graded properties in Ti-6Al-4V or a refined alpha grain size in gamma titanium aluminide alloys. Such microstructures can be developed during initial part manufacture or when parts are removed from service for inspection.

To lessen the cost of titanium sheet and foil products, the feasibility and kinetics of short time annealing treatments that could be done in line with cold rolling operations were determined. This work involved the derivation of an expression to describe recrystallization behavior during continuous, rapid heating in terms of that for isothermal heat treatment. The fit provided by such an expression was found to be very good for measurements in the Russian literature for cold rolled CP titanium (and low carbon steel) as well as those from our own work for the beta titanium alloy Timetal® 21S. The feasibility of short-time (recovery) annealing for cold rolled materials such as Ti-24Al-11Nb was also demonstrated.

Appendix: Publications, Presentations, Professional Activities, and Honors

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V. Seetharaman, R.L. Goetz, and S.L. Semiatin, "Dynamic Globularization of Lamellar Structures in a Near Gamma Titanium Aluminide Alloy," Recrystallization '99, Tsukuba, Japan, July, 1999.

S.L. Semiatin, "Advances in the Art and Science of Titanium Alloy Processing," Sauverur Lecture, Boston Chapter ASM, Cambridge, MA, October, 1999.

J.P. Simmons, C. Shen, and Y. Wang, "Phase Field Approach to Transformations Involving Concurrent Nucleation and Growth," MRS Fall Meeting, Boston, MA, November, 1999.

C.M. Lombard, A.K. Ghosh, and S.L. Semiatin, "Analysis of Cavitation in a Near-Gamma Titanium Aluminide During High-Temperature, Superplastic Deformation," MRS Fall Meeting, Boston, MA, November, 1999.

S.L. Semiatin and D.P. DeLo, "Microstructure and Texture Evolution During Equal Channel Angular Extrusion of Ti-6Al-4V," TMS Annual Meeting, Nashville, TN, March, 2000.

P.A. Kobryn and S.L. Semiatin, "The Effect of Interface Heat Transfer on Solidification, Microstructure Evolution, and Mold Wear During Permanent Mold Casting of Ti-6Al-4V," TMS Annual Meeting, Nashville, TN, March, 2000.

S.L. Semiatin, "Advances in the Art and Science of Titanium Alloy Processing," Clemson University, Clemson, SC, April, 2000.

P.A. Kobryn and S.L. Semiatin, "Microstructure and Texture Evolution During Laser Forming of Ti-6Al-4V," AeroMat 2000, Seattle, WA, June, 2000.

S.L. Semiatin and E.D. Roush, "Plastic Flow and Microstructure Evolution During Thermomechanical Processing of Laser-Deposited Ti-6Al-4V Preforms," AeroMat 2000, Seattle, WA, June, 2000.

T.J. Lienert, R. Wheeler, V. Seetharaman, and K.V. Jata, "Friction Stir Welding of Ti-6Al-4V Alloy," AeroMat 2000, Seattle, WA, June, 2000.

V. Seetharaman, K.V. Jata, and S.L. Semiatin, "Plastic Flow and Microstructure Development During High Temperature Deformation of a Friction Stir Welded 7050 Aluminum Alloy," Second Inter. Symposium on Friction Stir Welding, Gothenburg, Sweden, June, 2000.

S.L. Semiatin, "Deformation and Microstructure/Texture Evolution During Thermomechanical Processing of Titanium Alloys: Phenomenology, Mechanisms, and Modeling," Gordon Research Conference, Plymouth, NH, July, 2000; General Electric Aircraft Engines, Evendale, OH, July, 2000.

T.R. Bieler and S.L. Semiatin, "On the Origins of Flow Softening and Heterogeneous Deformation During Hot Working of Ti-6Al-4V," Plasticity 2000, Whistler, British Columbia, Canada, July, 2000.

P.A. Kobryn and S.L. Semiatin, "Laser Forming of Ti-6Al-4V: Research Overview," Eleventh Solid Freeform Fabrication Symposium, Austin, TX, August, 2000.

S.L. Semiatin, "Conversion of Alpha/Beta Titanium Alloys: Can Science Push Back the Frontiers Technology?," Allvac Corp., Monroe, NC, August, 2000.

S.L. Semiatin, "Flow Localization During Processes Involving Large Shear Strains: Equal Channel Angular Extrusion Versus Metal Cutting," COM 2000, Ottawa, Canada, August, 2000.

T.R. Bieler and S.L. Semiatin, "Texture Measurements and Simulation of Multi-Pass Hot Rolling of Ti-6Al-4V in the Two-Phase Temperature Range," COM 2000, Ottawa, Canada, August, 2000.

P.A. Kobryn and S.L. Semiatin, "Microstructure and Texture Evolution During Laser Forming of Ti-6Al-4V," "Best of Aeromat Session" at ASM Annual Meeting, St. Louis, MO, October, 2000.

J.P. Simmons, "Microstructure Development Under Nonisothermal Conditions Using the Phase Field Method," MRS Fall Meeting, Boston, MA, November, 2000.

N. Stefansson, S.L. Semiatin, and I. Weiss, "Kinetics of Static Globularization of Ti-6Al-4V," Thermec 2000, Las Vegas, NV, December, 2000.

O.M. Ivasishin and S.L. Semiatin, "Rapid Heat Treatment of Titanium Alloys – Principles and Applications," Thermec 2000, Las Vegas, NV, December, 2000.

S.L. Semiatin and T.R. Bieler, "Microstructure Evolution During Hot Working of Titanium Alloys," Symposium on Defect Properties and Mechanical Behavior of HCP Metals and Alloys, TMS Annual Meeting, New Orleans, LA, February, 2001.

T.R. Bieler and S.L. Semiatin, "Analysis of Primary Hot Working of Ti-6Al-4V Using Orientation Imaging," TMS Annual Meeting, New Orleans, LA, February, 2001.

S.L. Semiatin, "Material Behavior Models for Processing of Superalloys," AIM Workshop, GE Aircraft Engines, Evendale, OH, March, 2001.

P.A. Kobryn and S.L. Semiatin, "Microstructure and Texture Evolution During Solidification Processing of Ti-6Al-4V," International Conference on R&D in Net Shape Manufacturing, Birmingham, England, April, 2001.

S.L. Semiatin, "Advances in the Art and Science of Titanium Alloy Processing," Seoul National University, Seoul, Korea, May, 2001.

S.L. Semiatin and T.R. Bieler, "Effect of Preform Microstructure on Constitutive Behavior of Ti-6Al-4V under Conventional Hot-Working Conditions," LiMAT 2001 Conference, Pusan, Korea, May, 2001.

K.V. Jata, "Structure-Property Relationships in Friction-Stir Joined High-Strength Aluminum Alloys," LiMAT 2001 Conference, Pusan, Korea, May, 2001.

M.G. Glavicic, S.L. Semiatin, and P.A. Kobryn, "Texture Evolution during Casting of Ti-6Al-4V Ingots," AeroMat 2001, Long Beach, CA, June, 2001.

P.A. Kobryn, S.L. Semiatin, and M.G. Glavicic, Texture Evolution During Laser Deposition of Titanium," AeroMat 2001, Long Beach, CA, June, 2001.

R.L. Goetz, K.V. Jata, and S.L. Semiatin, "Modeling Material Flow in Friction Stir Welding Using FEM," AeroMat 2001, Long Beach, CA, June, 2001.

P.A. Kobryn and S.L. Semiatin, "Mechanical Properties of Laser-Deposited Ti-6Al-4V," Twelfth Annual Solid Freeform Fabrication Symposium, Austin, TX, August, 2001.

Professional Activities:

Member, TMS-AIME Shaping and Forming Committee (S.L. Semiatin, V. Seetharaman)
Member, ASM Phase Transformations Committee (J.P. Simmons)
Chapter Chairman, Dayton Chapter, ASM International (V. Seetharaman)
Chairman, Scholarship Committee, Dayton Chapter, ASM International (S.L. Semiatin)
Reviewer, Metall. and Mater. Trans., Acta Mater., Scripta Mater., Trans. ASME, Mater. Sci. and Eng., J. Mater. Proc. Tech. (S.L. Semiatin, V. Seetharaman)
Assoc. Editor, J. Mater. Eng. and Performance (V. Seetharaman)
Reviewer, J. Amer. Ceram. Soc. (R.E. Dutton)
Adjunct Professor, Industrial, Welding, and Systems Engineering Department, Ohio State University (S.L. Semiatin)
Adjunct Professor, Chemical and Materials Engineering Department, University of Dayton (S.L. Semiatin)
Adjunct Professor, School of Graduate Studies, Wright-State University (S.L. Semiatin)

Honors

Fellow, ASM International (S.L. Semiatin; inducted 11/92)
Fellow, ASM International (V. Seetharaman; inducted 10/96)
Fellow, ASM International (K.V. Jata; inducted 10/98)
Fellow, Air Force Research Laboratory (S.L. Semiatin; inducted 11/93)
Air Force Basic Research Award for 1995 (S.L. Semiatin)
Honorary Member, Alpha Sigma Mu, 1996 (S.L. Semiatin)
Top Referee Award, Scripta Materialia/Acta Materialia, 1998, 2000 (S.L. Semiatin)
Albert Sauveur Memorial Lecturer, ASM Boston Chapter, 1999 (S.L. Semiatin)
Lifetime Achievement Award in Processing, Thermec'2000, 2000 (S.L. Semiatin)

Extended Scientific Visits From and to Other Laboratories

Prof. K. Ashbee, School of Metallurgy and Materials, University of Birmingham (UK), visited AFRL (Processing Science Group) from 7/95 to 6/96.

Prof. M. Rahaman, Ceramic Engineering Department, University of Missouri, Rolla, visited AFRL (Processing Science Group) from 6/96 to 8/96; 6/2001 to 8/2001.

Professor A.K. Ghosh, Department of Materials Science and Engineering, University of Michigan, visited AFRL (Processing Science Group) from 9/97 to 7/98.

Dr. F. Montheillet, Director of Research, Plasticity/Damage/Corrosion of Materials, Centre Science des Materiaux et des Structures, Ecole des Mines de Saint-Etienne, visited AFRL (Processing Science Group) from 6/98 to 7/98.

Professor T.R. Bieler, Department of Materials Science and Mechanics, Michigan State University, visited AFRL (Processing Science Group) from 6/98 to 8/98; 1/1/99 to 12/31/99; 6/2001 to 8/2001.