Spring 2006

Center for Innovative Sintered Products

CISP

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CISP 2006—New Collaborations and Opportunities

Dr. Judith A. Todd

Welcome to the Spring 2006 edition of the CISP newsletter. Following the recommendations of the CISP Advisory Board, we are pleased to announce a year full of new collaborations and opportunities.

As we move forward, the CISP leadership team will comprise Judy Todd, Acting Director; Ivi Smid, Associate Director for refractory and hard materials, nanocomposites, and new materials initiatives; and Donald F. Heaney, Associate Director. Chantal Binet will serve as the Materials Research Engineer. Tracy Potter will serve as Director of Operations for the CISP laboratories, and Kristina Cowan will serve as Manager of Materials Testing and Services. Engineering Science and Mechanics (ESM) staff, Diane Bierly and Kelly Owens, are assisting with CISP administration. John Johnson has been appointed Adjunct Professor of Engineering Science and Mechanics, and, together with Sharon Elder, Research Assistant, will lead our collaboration and student exchange program with a visit to Tsinghua University in June. Sharon is coordinating summer visits for five Penn State students as part of Rand German's NSF program to exchange students with Dr. Jose Torralba's group at University Carlos III in Madrid, Spain.

New research programs are being initiated on refractory nanocomposites, powder injection molded and sintered MEMS devices, controlled density refractory metals, tungsten heavy alloys, and lubricants for press and sinter applications. 2006 is off to a great start.

CISP is now adding Faculty Associates with expertise in areas recommended by the CISP Industry Council. Barbara Shaw brings expertise in aluminum and magnesium alloys and their corrosion behavior; Joe Rose and Bernie Tittmann are world-acclaimed experts in nondestructive evaluation; Steve Fonash, Jeff Catchmark, Melik Demirel, and Jian Xu bring expertise in nanoparticulates and nanotechnology; Dinesh Agrawal is a leading authority in microwave technologies; Al Segall brings expertise in tribology and hard coatings; John Hellman is internationally recognized for his ceramics research; Mark Horn, Mike Lanagan, and Tony Huang bring new sensor technologies; and Kevin Koudela and Cliff Lissenden add new expertise in composite materials.

We are strengthening our ties with the Applied Research Laboratory (ARL) in the areas of gears, composites,

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Inside This Edition

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Upcoming Events

April 25-26, 2006
Industry Member Meeting
University Park, PA

May 2-3, 2006
MPIF PM Sintering Seminar
Cleveland, OH

June 18–21, 2006
PowderMet 2006
San Diego, CA

October 16-19, 2006
ASM-TMS-ACerS MS&T '06
Cincinnati, OH

Pre-competitive project progress for the quarter

Multiple Axis in situ Monitoring (M.A.I.S.M.)—
Laser Dilatometry of Polymer Burnout

Debinding kinetics are currently being evaluated using a 45000 BTU gas fired burner. Last quarter the M.A.I.S.M project progressed to using this gas fired burner, 'the Rocket Launcher' to monitor the mass of the part during the thermal cycle. This allows several capabilities that were limited on the M.A.I.S.M. laser dilatometer. With the burner rig, video imaging and trials can be done in a more aggressive process atmosphere, while the M.A.I.S.M. was restricted to a neutral atmosphere, and we now have the ability to collect data on weight and weight changes. Early efforts focused on stabilizing the equipment to create a better reading for the scale with the goal of being able to measure the addition of mass through oxidation or atmospheric moisture during the thermal cycle.

Current experiments involve the observation and video capture of binder 'burn-out' at various temperatures with maximum temperature differential (cold part inserted into a hot furnace) and using standard ramp-style furnace profiles as well as the interaction between thermal gradients from surface-to-center and the formation of liquid decomposition products on the part surface. Debinding efficacy is evaluated via changes in mass, as well as TGA of 'debound' parts.

Future experiments will focus on the development of the most efficient binder burn-out process via optimization of thermal treatment based on heat and mass transfer theory. Additionally, the effect of powder type on binder removal will be evaluated.

Press and Sinter Realities of Nanoscale Powders

The press and sintering behavior of two commercially available fine molybdenum powders having BET particle diameters 1.2 and 0.8 μm were compared. As expected, the 0.8 μm powder exhibited a slightly poorer compressibility than the 1.2 μm powder; however, it exhibited a much higher sinterability. Under hydrogen sintering, the 1.2 μm powder was sintered to a maximum 95.7% of the theoretical density when sintered at 1400°C for 4 hours; the 0.8 μm powder was sintered to 99% of theoretical density and at the same time and temperature. *Figure 1 (next page)* compares the sinter density of the two powders at different times and temperatures. Further

Members voted to award several precompetitive projects for the upcoming year

- Press and Sinter Processing Realities with Nanoscale Powders (nano-P/M)—*Randall M. German*
- Technical and Economical Comparison of Micro Powder Injection Molding—*Seong Jin Park* and *Randall M. German*
- Microstructural Evolution in Liquid Phase Sintering—*Jianfeng Guo* and *Randall M. German*
- Binder Removal in Nitrogen/Hydrogen Atmospheric Mixtures—*Chantal Binet*
- Detailed Linkages from Powder Characteristics to Properties in Press-sinter Processing of Parts—*Randall M. German*, MSU

Presentations and Papers

Selected Papers, Publications and Conference Presentations

John L. Johnson; Donald F. Heaney

"Processing of Biocompatible Materials via Metal and Ceramic Injection Molding"
Medical Device Materials II , pp. 325-330. 2005

Donald F. Heaney

"Fabrication Techniques for the Production of Porous Structures"
Medical Device Materials III , ASM Medical Device Conference. 2005.

John L. Johnson and Donald F. Heaney

"Metal Injection Molding of Co-28Cr-6Mo"
Medical Device Materials III , ASM Medical Device Conference, 2005.

Donald F. Heaney and Timothy Eden

"Residually Stressed Multiple Layer Tungsten Heavy Alloys by Metal Injection Molding"
Proceedings of the 2005 International Conference on Powder Metallurgy and Particulate Materials, Metal Powder Industries Federation, Princeton, NJ, 2005, pp. 8.61-8.71.

Randall M. German, Donald F. Heaney, and J. L. Johnson

"Bi-Material Components Using Powder Injection Molding: Densification, Shape Complexity, and Performance Attributes"
Proceedings of the 2005 International Conference on Powder Metallurgy and Particulate Materials, Metal Powder Industries Federation, Princeton, NJ, 2005, pp. 4.41-4.52.

Brad A. Gething, Donald F. Heaney, Donald A. Koss, and T. J. Mueller

"The Effect of Nickel on the Behavior of Molybdenum P/M Steels"
Material Science and Engineering A, 390, 2005, pp. 19-26.

Deborah Blaine, John D. Gurosik, Seong Jin Park, Donald F. Heaney, Randall M. German

"Master Sintering Curve Concepts as Applied to the Sintering of Molybdenum"
Metallurgical and Materials Transactions A, vol. 37A, March 2006, pp. 1-6.

C. D. Greene and Donald F. Heaney

"The PVT Effect on the Final Sintered Dimensions of Powder Injection Molded Components"
Materials & Design, In Press, Corrected Proof, Available online 26 August 2005.

Chantal Binet, Donald F. Heaney, R. Spina, and L. Tricarico

"Experimental and Numerical Analysis of Metal Injection Molded Products"
Journal of Materials Processing Technology, vol. 164-165, 2005, pp. 1160-1166.

Pre-competitive project progress

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investigation is underway to determine the sintering behavior of the powders in vacuum sintering as well as grain growth and mechanical properties of the sintered compacts. Dilatometer analysis was performed to study the effect of compaction behavior on the densification behavior of the molybdenum powders using the *Masters Sintering Curve* (MSC) approach. These results were used to construct the MSC as shown in Figure 2. The surface can be used to completely map the densification (Ψ) occurring in a compact in terms of the compaction pressure and the sintering parameters (which are contained within the work of sintering, Θ). Further study is underway to develop a similar surface for 0.8 μm molybdenum powder.

Figure 1: Comparison of densities achieved during press and sintering of the two molybdenum powders.

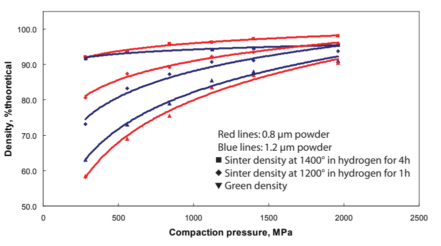
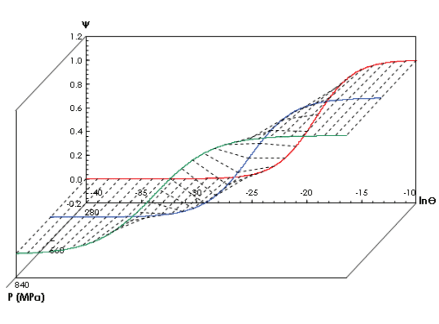


Figure 2: Master Sintering Curve (MSC) for the 1.2 μm molybdenum powder sintered in hydrogen.



How is Tooling Produced for MEMS Scale Micro Injection Molding?

The utilization of lithography to form micro component tooling is being practiced at CISP. Technology developed to manufacture integrated circuits is being utilized. A typical integrated circuit is fabricated by photolithography. For this technology, radiation sensitive polymeric materials called *resists* are used to produce circuit patterns on the substrates. The resist film is subsequently exposed in an image-wise fashion through a mask (in photo- and X-ray lithography) or directly with finely focused electron beams. The exposed resist film is then developed, typically by immersion in a developer solvent to generate three-dimensional relief and to expose the desired feature

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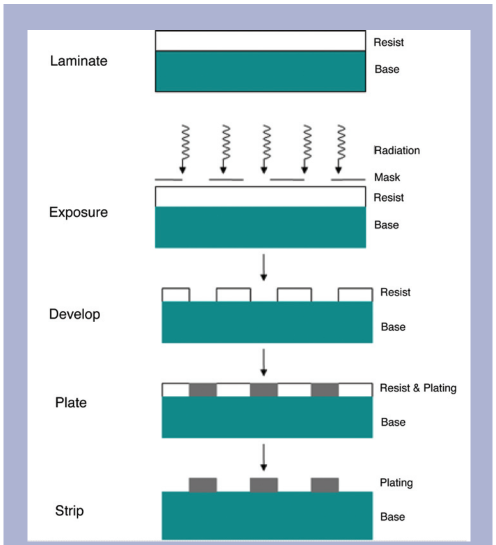

Figure 3: Lithographic Process for the Production of Tooling Inserts

Accomplishments

Ravi Bollina completed his defense on the in situ evaluation of supersolidus liquid phase sintering phenomena. Ravi Bollina has accepted a position with a member company, Plansee, Austria.

Ravi Kumar Enneti completed his defense on Thermal Analysis and Evolution of Shape Loss Phenomena During Polymer Burnout in Powder Metal Processing.

Dr. Randall M. German, Director of the Center for Innovative Sintered Products at the Pennsylvania State University has accepted a new position as Director for the Center for Advanced Vehicular Systems and Chaired Professor of Mechanical Engineering at Mississippi State University. He will continue to advise his graduate students at PSU through degree completion.

Donald F. Heaney, the Associate Director for CISP, has earned his PA Professional Engineering License. Don passed the P.E. exam last October and received his license in February 2006. He is a third generation P.E.: his late grandfather was a P.E. in Chemical Engineering and utilized his license in developing freeze drying technology for Nestle's; his late father was a P.E. in Civil Engineering and designed and built sewage treatment plants for the iron and steel processing industry; and now Don is a P.E. in Metallurgical Engineering. Don plans to continue his family legacy and utilize his PE license to expand the use of powder processed materials in the medical, military, and automotive markets. His current areas of interest are in micro-miniature device fabrication utilizing micro EDM and lithography techniques, titanium P/M processing, utilization/understanding of polymers for net shape fabrication, and alloy development for predictable fracture behavior and process independent strengthening. For more information, please contact Dr. Heaney at dfh100@psu.edu or 814-280-0627.

Tooling for MEMS Scale MIM

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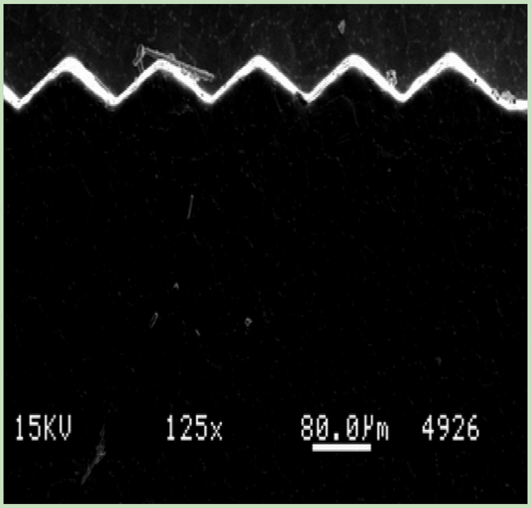

Figure 4: Lithographic MIM Component Detail

detail on the metal substrate. The exposed substrate acts as a cathode for plating. Figure 3 depicts the lithographic process sequence. Hard nickel is the preferred material for microtooling fabrication since it is one of the hardest materials that can be plated in high thicknesses.

The feasibility of powder injection molding technology to form smaller size features is primarily controlled by tooling resolution, the ability to fill the mold, and the ability to remove the component from the tooling. Web thicknesses in the 0.001″ range are possible; however, difficulty in removal from the tooling may arise if the web is forming a blind hole that will cause a vacuum upon removal from the tool. The technology has a limit on feature resolution due to minimum particles size. The smaller the particle size, the better the surface finish and the smaller the feature size. Our findings show that the surface finish will be 2-3 times as rough as the particle size used. A radius of 0.0015″ is the current capability of the technology. Figure 4 shows a photo micrograph of a µMIM feature produced from lithographic tooling. For more information on the capability of this technology and its current uses, contact Donald F. Heaney at dfh100@psu.edu.

Microwave Heating Technologies

Microwave sintering of WC-Co was explored with the Willert-Porada group in Germany, first at the University Dortmund, and later at the University of Bayreuth. The technology was developed and commercialized at Penn State in collaboration with Malon Dennis (Dennis Tool). Sintering of tungsten carbide cobalt (WC-Co) is an early technology to have emerged in a comprehensive continuous microwave sintering system.

Dennis Tool developed a process and turnkey equipment, which they are currently using to produce WC-Co drill bits for mining applications. The microwave fired drill bits are being sold commercially through Dennis Tool. The bits have demonstrated improved properties—better wear and impact resistance in the field when compared to conventionally sintered parts. The microwave system, similar to a Stokes press design, does not use susceptors, but couples directly with the WC-Co for fast direct heating. This microwave furnace technology may require a more highly trained operator compared to conventional furnaces. Other microwave/microwave-hybrid systems may be more problematic, and this could cause conflicting reports concerning property improvements.

The Catholic University of Leuvan and a Fraunhofer facility are using a microwave- hybrid system, combining microwaves with conventional heating. The Catholic University is using microwave-hybrid heating (microwave and radiant heat from a susceptor) to heat materials that do not readily absorb microwave energy. Susceptors can be used to heat samples to a high enough temperature so that direct microwave coupling can occur.

A Fraunhofer facility is using microwave-assist technology (simultaneous application of microwave and gas or electric heat). Microwave-assist is a technology patented by C-Tech Innovations (formerly EA Technologies). Ceralink has the exclusive North American license to use and sublicense this technology, and they have witnessed a growth in interest and application of microwave heating for the metals industry. Ceralink has been involved with continuing research interests in microwave brazing, sintering, binder removal, drying, melting and forming of metals. Their service allows companies to explore feasibility in a private Microwave Testing Center, in addition to assisting with cost-benefit analysis and scale-up.

For an overview of microwave applications, refer to *Advancements in Microwave Heating Technology* in the January 2005 issue of *Industrial Heating*.

Morgana Fall <info@ceralink.com>

Spring IMM

The next CISP Industrial Members Meeting will be held at—

The Atherton Hotel
125 S. Atherton Street
State College, PA
April 25 and 26, 2006

Speakers include
Stephen J. Fonash
Jogender Singh
Dinesh Agarwal
more…

HVPC spray system

High-Velocity-Particle-Consolidation (HVPC) of Ni-based Self-Lubricating Composite Coatings on Ti-6Al-4V.

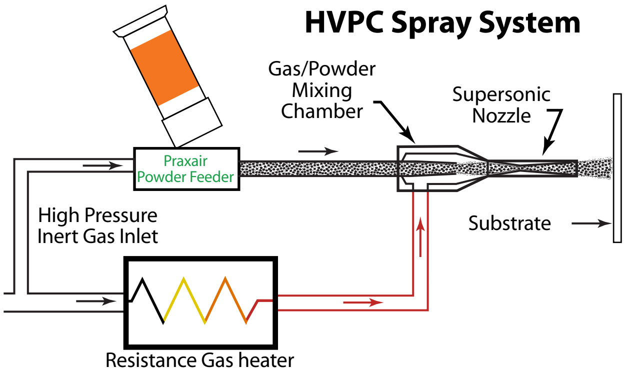

Figure 5: Schematic of the experimental system.

A self-lubricating composite coating using nickel (Ni) and molybdenum-di-sulfide (MoS_2) has been developed for the protection of dovetail contact of turbine blades from fretting wear. While Ni provides wear resistance, MoS_2 particles impart lubricating properties to the coating. The coatings have been deposited using the *High Velocity Particle Consolidation* technique based on the *Cold Spray Method*.

Cold spray is a relatively new coating method for deposition of metals, alloys, polymers and composite powder-materials onto various substrates. Due to the use of low temperatures, the absence of in-flight oxidation and other chemical reactions, thermally vulnerable materials can be deposited without significant material degradation using this method.

The jet temperature range for cold spray lies between 0°C and 700°C, which is usually lower than the melting or softening temperature of the candidate powder and substrate materials. Cold spray appears to be a promising coating method for composite materials, wherein attractive properties of the individual powder materials are retained in the coatings.

Commercially available Ni and MoS_2 were used as starting materials, and feedstock powders of varying compositions are used. All feedstock powders were prepared by admixing 16µm Ni powder with different amounts (2wt%, 3wt%, 4wt%) of MoS_2 powders, followed by oven-drying. Coating experiments are being carried out using the HVPC system developed at the Material Processing Division of the Applied Research Laboratory (Figure 5).

Feedstock powder was injected into the gas flow at the nozzle intake and accelerated through a convergent-divergent De-Laval type of nozzle (WC, length 211 mm and throat 3 mm). A gas heater *(Miller, 652 Welder)* was employed to increase the gas temperature to 500ºC. During deposition, the spray gun was manipulated by a robot (Fanuc, LR 100i). Plastic deformation of particles upon impact produced high strength bonds between the powder and the substrate. Pure nickel was sprayed to establish conditions for the build up of dense nickel coatings on Ti-6Al-4V substrates. These conditions *(Table 1)* were later used for experiments with Ni-MoS_2 powder.

Table 1: Set of spray conditions

Process gas	Nitrogen
Gas temperature	500ºC
Gas pressure	2.4 MPa
Spray distance	12.5 mm
Spray gun velocity	19 mm/sec
No. of overlaps	3-3-6 and 9-9-18

A high magnification view of cross sections of the coating by secondary electron microscopy is shown in Figure 6. In order to verify the presence of MoS_2 in the coating, EDS of the coating was performed.

A critical maximum amount of MoS_2 (Figure 7) which can be incorporated into the coating via admixed feedstock was found to be 4 wt%. The weight of coating deposited decreases as the amount of MoS_2 in the feedstock increases (Figure 8). Such a result is indicative of the fact that MoS_2 inhibits the build-up of coating.

Figure 9 *(back cover)* represents the effect of the amount of lubricant and overlaps on the coating thickness. Irrespective of the number of overlaps, the coating thickness decreases with increasing amounts of MoS_2. The effect of the number of overlaps, however, depends upon the composition of the coating.

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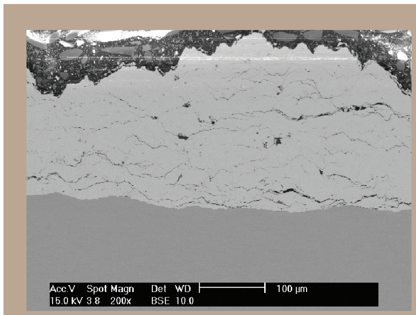

Figure 6: SEM and EDS of Ni-2wt% MoS_2 coating cross section

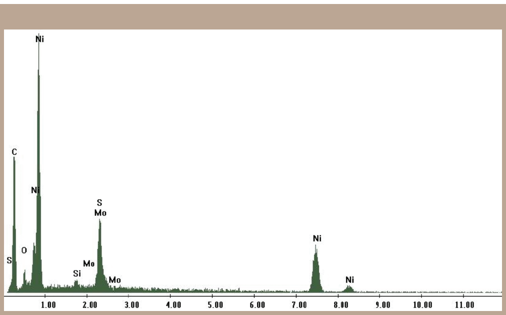

Figure 7: EDS of coating

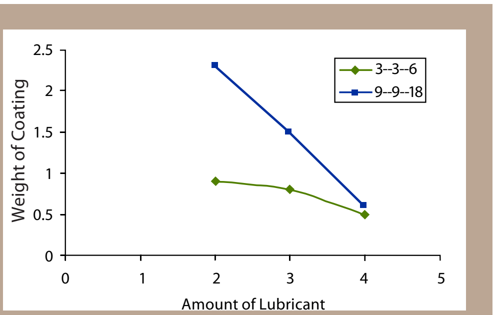

Figure 8: Weight of coating deposited vs. amount of lubricant at various no. of overlaps.

Grain Growth Behavior of Tungsten Heavy Alloy

Based on Master Sintering Curve Concept

H. Su and D. L Johnson [1] developed the master sintering curve as a practical way of describing the densification of a compact along any given complex sintering cycle. In this work, the concept of the *Master Sintering Curve* has been successfully extended to describe the grain coarsening of WHAs, both during solid state and liquid phase sintering.

The classical law for grain growth by Ostwald ripening [2, 3] establishes that $G^3 \propto t$, where G is the mean grain size and t is the time. This expression in differential equation form is equal to:

$$\frac{dG}{dt} = \frac{K}{G^2} \quad (1)$$

where K is given by:

$$K \propto \frac{DC\Omega\gamma}{RT} f(V_l) \quad (2)$$

In this last expression, D is the diffusivity of the particle atoms into the matrix, C the particle atoms' solubility in the matrix, Ω the particle atoms' molar volumen, γ the particle-matrix surface energy, R the universal gas constant, T the absolute temperature, and $f(V_l)$ is a function of the liquid volume fraction (V_l) introduced to take into account the non infinite dilution of the system and coalescence effects. Between the various models existing to consider these effects [4, 5], the following expression proposed by German [6] is going to be used in this work:

$$K = K_I + \frac{K_{II}}{V_l^{2/3}} \quad (3)$$

where K_I and K_{II} are terms including the influence of temperature, diffusivity, solubility, atomic volume, surface energy and other unknowns. As diffusivity D depends exponentially on temperature (Arrhenius' law), so does K:

$$K = K_0 \exp\left(-\frac{Q}{RT}\right) \quad (4)$$

where K_0 is the associated pre-exponential factor and Q the activation energy for the diffusion process. Combining equations (3) and (4):

$$K = \left(K_{I0} + \frac{K_{II0}}{V_l^{2/3}}\right) \exp(-Q/RT) \quad (5)$$

where K_{I0} and K_{II0} are constants including the several material parameters.

Substituting equation (5) in (1) and integrating:

$$G^3 = G_0^3 + 3\int_0^t \left(K_{I0} + \frac{K_{II0}}{V_l^{2/3}}\right) \exp\left(-\frac{Q}{RT}\right) dt \quad (6)$$

Equation (6) for grain growth is transformed into the master sintering curve form as:

$$G = \sqrt[3]{G_0^3 + 3\Theta} \quad (7)$$

where

$$\Theta = \int_0^t \left(K_{I0} + \frac{K_{II0}}{V_l^{2/3}}\right) \exp\left(-\frac{Q}{RT}\right) dt \quad (8)$$

The parameters K_{I0}, K_{II0}, and Q can be determined by curve fitting of experimental data with equations (7) and (8). The condition imposed in this fitting is to minimize the following mean residual:

$$R(K_{I0}, K_{II0}, Q) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{G_{MSC\_i}}{G_{EXP\_i}} - 1\right)^2} \quad (9)$$

Debinding Furnace Donated to CISP

Kennametal continues their support of CISP activities by donating a Go-Ceram debinding furnace. This furnace offers a unique capability of highly controlled vacuum debinding.

CISP plans to install and evaluate this furnace for both MIM components and also highly reactive pressed components such as titanium.

Contact Donald F. Heaney (dfh100@psu.edu) or Tracy Potter (tjp4@psu.edu) to find out more or to schedule a service run.

Go-Ceram Vacuum Debinding Furnace

where R is the mean residual, N the number of experimental grain size data, i a dummy variable for summation, G_{MSC_i} -ith grain size predicted by MSC model with given K_{I0}, K_{II0}, and Q, G_{EXP_i} -ith grain size experimentally measured. As in the case of densification, the practical advantage of the master sintering curve applied to coarsening is to predict grain growth during a quite complicated thermal sintering cycle with a very limited amount of experiments done under isothermal conditions, or at a constant heating rate.

Grain size measurements during liquid phase sintering for three different amounts of solid phase are presented in *Figure 10a*. *Figure 10b* presents the master sintering curve built from the data of *Figure 1a* using the equations (7), (8), and (9) as explained previously. Regardless of their sintering time and temperature, all the data are placed on a single curve. The values obtained for the rate constants (K_{I0} and K_{II0}) and activation energy (Q) for each composition is listed in the following table:

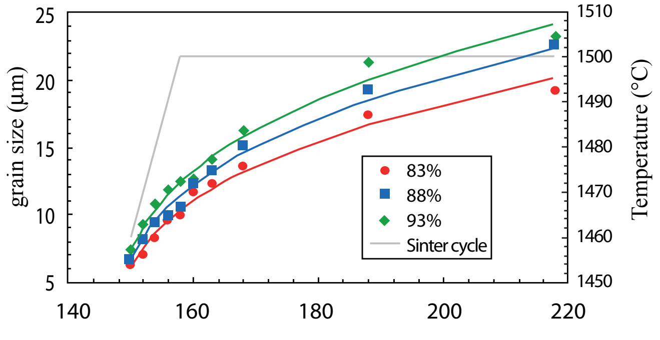

Figure 10a

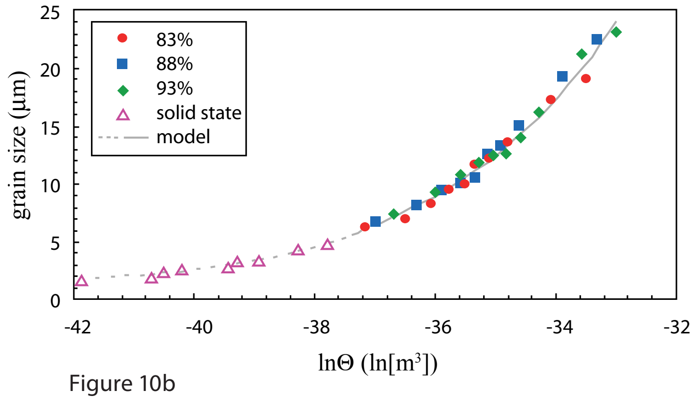

Figure 10b

Alloy	Liquid Phase Sintering			
	Q (kJ/mol)	K_{I0} (μm³/s)	K_{II0} (μm³/s)	mean residual
83 % WHA	106	$5.53 \cdot 10^{-1}$	$4.06 \cdot 10^{-2}$	3.82 %
88 % WHA				
93 % WHA				

The fit between experimental data and the master sintering curve is good, as indicated by the low mean residual values.

The activation energy for grain growth, 106 kJ/mol, is similar to the values obtained in a previous work for densification, between 101 and 136 kJ/mol [7]. These values are coherent with a dominant densification and coarsening processes controlled by dissolution-reprecipitation.

In order to identify critical parameters in grain growth-behavior during sintering, a dimensionless sensitivity is defined as follow:

$$\text{Sensitivity} \equiv \frac{\text{change in final grain size}/\text{reference value of final grain size}}{\text{change in input parameter}/\text{reference value of input parameter}} \quad (10)$$

Sensitivity values calculated in this way are useful in order to modify experimental parameters with the aim of getting high density with minimum grain coarsening. Sensitivity analysis showed that grain growth is especially sensitive to the sintering temperature and the activation energy for the diffusion process through the liquid phase. The sintering time and the material parameters included in the pre-exponential factor (diffusivity and solubility) have a moderate influence. The final grain size is almost unaffected by the initial grain size and the processes happening in solid state during the heating ramp. Finally, sensibility values are similar for the three compositions, indicating that the amount of liquid at high temperature is not critical, either.

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J. M. Martin <jmm64@psu.edu>
J. F. Guo <jxg957@psu.edu>

References

[1] H. Su and D. L. Johnson, "Master Sintering Curve: A Practical Approach to Sintering", *Journal of American Ceramic Society*, Vol. 79, pp. 3211-3217, 1996.

[2] I. M. Lifshitz and V. V. Slyozov, "The Kinetics of Precipitation from Supersaturated Solid Solutions", *J. Phys. Chem. Solids*, Vol. 19, No. 1/2, pp. 35-50, 1961.

[3] C. Wagner, "Theorie der Alterung von Niederschlägen durch Umlösen (Ostwald-Reifung)", *Z. Elektrochem.*, Vol. 65, No. 7/8, pp. 581-591, 1961.

[4] P. W. Voorhees, "Ostwald Ripening of Two-Phase Mixtures", *Annu. Rev. Mater. Sci.*, Vol. 22, pp. 197-215, 1992.

[5] R. M. German and E. A. Olevsky, "Modeling Grain Growth Dependence on the Liquid Content in Liquid-Phase-Sintered Materials", *Metall. Mater. Trans. A*, Vol. 29A, pp. 3057-3067, 1998.

[6] R. M. German, "Microstructure of Gravitationally Settled Region in a Liquid-Phase Sintered Dilute Tungsten Heavy Alloy", *Metall. Mater. Trans. A*, Vol. 26A, pp. 279-288, 1995.

[7] S. J. Park, J. M. Martin, J. F. Guo, J. L. Johnson, and Randall M. German, "Densification Behavior of Tungsten Heavy Alloy Based on Master Sintering Curve Concept", submitted for publication in *Metallurgical and Materials Transactions A*.

…see also CISP Newsletter Fall 2005

Transitions

Until We Meet Again

Sharon Elder

Research Assistant

Now that 2005 is an event to remember and 2006 is one to anticipate, I am positioning for another view. Much as I have enjoyed working with the P/M industry, I am intrigued by doing something different. I recently accepted a position as the Director of Program Development at the Energy Institute here at Penn State. I reflect over the past seven years and cannot begin to explain the lessons learned. I have a greater appreciation for this industry and its importance to our nation. P/M importance in the automotive, aerospace, telecommunications, electronics and the biomedical worlds continues to grow. With growth comes opportunities and challenges. I am more aware of the challenges that the industry faces—not only from foreign competition—but at home, also. Regulations and attacks on products make it ever more difficult to compete or stay in business. Globalization means workers must face competitors who live a mouse-click away in Germany, China, India, Africa or countless other places. Bringing this back to CISP, I realize that each and every individual company made an impact on the center. As Kate Devine so aptly stated, the goal is not that all people have the exact same vision, but several different visions coordinated and harmonized into one whole that is much greater than the parts, and infinitely more adaptable and powerful. An orchestra or ensemble is great not because it is all the same instrument, but precisely because it is different instruments brought together in their different interpretations of the same piece. That was the duty of CISP—to bring together the different pieces to work under a single umbrella.

The bottom line is that we are all part of a dynamic and diverse industry that plays a vital role in the country's economy, defense, and other areas. As I assume my new position, I will be gaining new knowledge, new industry partners and looking forward to continuing the relationship with many of you. For this I can only say—'til we meet again.

Sharon Elder <sle9@psu.edu>

CISP 2006

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NDE, tribology, cold spray, laser cladding, and laser technologies. Through such collaborations, CISP members will have the opportunity to engage in basic research projects with CISP faculty and students and develop translational technologies, particularly for defense applications with ARL. Together, we will have a powerful team that can leverage major funding opportunities to the benefit of CISP and our industry members.

There will be opportunities to meet many of our Faculty Associates at the next CISP meeting to be held at the Atherton Hotel on April 25-26, 2006. Please make your reservations now and look out for the meeting agenda.

I look forward to seeing you there.

Judith A. Todd <jtodd@psu.edu>

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HVPC spray system

…continued from page 5

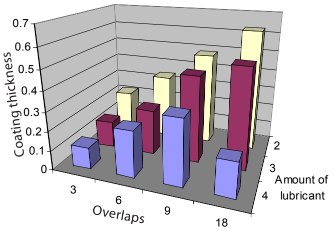

Figure 9: Coating thickness as a function of amount of lubricant and number of overlaps.

While coatings with 2 and 3 wt% MoS_2 benefit from increasing number of overlaps, there is a sharp decrease in coating thickness in case of coating with 4 wt% MoS_2.

It was concluded that self lubricating composite coatings can be deposited using the Cold Spray Method. Alternative feedstock preparation techniques wherein MoS_2 is mechanically or chemically bonded to Ni before spraying such as milling and powder coating are being explored to increase the amount of MoS_2 in the coating.

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