Fall 2003

Center for Innovative Sintered Products

CISP

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Right Time, Right Place

Sharon Elder – Executive Director

What is really happening in this industry? I believe it is safe to say the Center has followed it through one of the most difficult cycles the industry has witnessed. Consolidations, bankruptcies, restructurings, facility closings, personnel changes and other major business events have often left customers unsure, questioning, and sometimes in the lurch. Without any doubt, the number one issue domestically is our economic state. As we head into an election year, we are seeing posturing from both the Republicans and Democrats over the strength of the economy and what will be the driving forces over the next four years. There are higher expectations of science and technology than ever before, especially as drivers of our economy. This is a position not to be taken lightly as the research that is done today will lay the foundation for new products in 5-10 years. Making the right moves now will assure a future. The demand for goods depends to a large extent on consumer confidence, which in turn drives corporate spending. We must make sure we are positioned for the upturn, as supply never keeps up with demand when the economy rebounds. Right now we are seeing no excess in the supply chain so we can expect a bottleneck when things change. When growing demand exceeds supply, prices will stabilize or increase. Be prepared: as investors see where they are heading and it appears the ship is finally on course, the cycle will start all over again and once business does return, so will venture capital.

I have been asked how CISP is surviving without funds from the Commonwealth. Seed funds were great but we always knew we would eventually need to move towards self-sustainability – we just did not anticipate moving 2 years early. Our success stems from our ability to bring together companies, academic institutions, industry bodies and national laboratories to co-operatively develop networks that will make this industry more competitive. We have been able to transition in much the same way that companies sell maintenance and service contracts, i.e. the add-ons, the upgrades to make a machine run better, and the extended warranty. We look at joining the Center as the first step in forming a long-term relationship. This offers an excellent opportunity to access our capabilities and specialized expertise and identify a company-specific project. It is at this company-identified level where we are mission-critical partners offering a spectrum of services covering a wide range of topics geared towards solutions.

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Center for Innovative Sintered Products

Including Strength in Sintering Simulations

In situ strength evolution during sintering has been a hot topic in CISP over the past several years. Greg Shoales's, Xiaoping Xu's and Connie Schlaefer's PhD theses bear witness to this. Research focusing on simulating sinter densification and shrinkage has also been followed for many years by Dr. German's students, but it is only recently that the finite element models using the continuum theory of sintering have been explored by PhD candidate Debby Blaine.

These models have the ability of simulating 3-dimensional shrinkage and distortion of powder components during sintering. However, one of the fundamental issues surrounding this style of modeling is that it does not include the influence of *in situ* strength on sintering behavior. Research has shown that the *in situ* strength significantly influences the sintering shrinkage and distortion. A simple example of this phenomenon can be illustrated through bending beam experiments.

continued on pg2

Upcoming Events

October 20-21, 2003
CISP Industry Member Meeting
University Park, PA

March 21-24, 2004
PIM04
Orlando, FL

June 13-17, 2004
MPIF PM^2Tec
Chicago, IL

Green Body Heterogeneity and Dimensional Precision

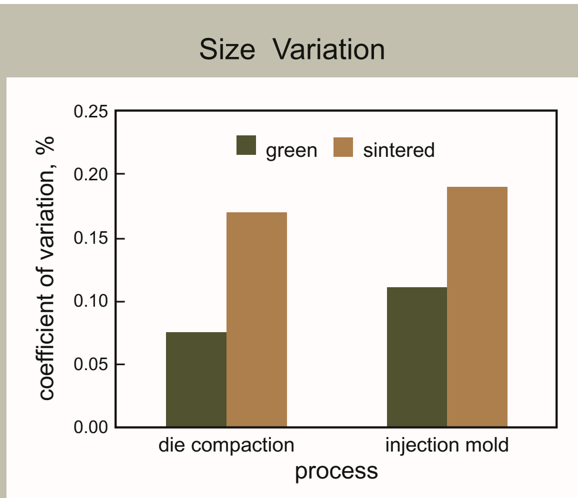
A new mathematical analysis has been created to examine the sources of sintered dimension variation using statistical data from a few earlier CISP studies (die compaction, injection molding) to identify the dominant factor. The approach is leading to a mathematical translation of sintered dimensional tolerances into specifications on the green body mass repeatability, ignoring warpage.

> This means that deviatoric factors that cause a loss of geometric spacial relations have been eliminated, including
>
> - density gradients in the green body
> - thermal gradients from aggressive heating cycles
> - internal vapor pockets during polymer burnout cycles that generate stress
> - gravity-induced gradients due to substrate friction or improper support.
>
> Accordingly, in the absence of warpage the producer is still faced with two issues:
>
> 1. prediction of final size to "center" the dimensions
> 2. control of the scatter to hold production within the "tolerance" range.

Industrial components are often specified to a tight clustering around the centered dimension. In many cases the allowed dimensional tolerance zone might be ±0.2% (plus and minus three or six standard deviations). This dimensional tolerance zone is tighter in applications associated with sintered cutting tools, fiber optic connectors, microelectronic packages, automotive drive trains, fuel injectors, and hydraulic fluid control.

After analysis of several data sets, such as that shown in the figure below for stainless steels by die compaction and injection molding, the feature leaping out of the statistical analysis is mass variation in the forming machine, both for die compaction and injection molding.

Variation between the green and sintered states of die compacted and injection molded stainless steel.



In analysis of data on cemented carbides, stainless steel and steel, generally the mass variation in the green body accounts for 70 to 90% of the sintered dimensional variation. This sets some new goals for the powder community in terms of improved uniformity in powder flow, improved feedshoes, more uniform and stiffer tooling and forming machines, and so on. However, the most important finding is that most of the dimensional variation in the sintered product has its origin in the mass metering at the forming machine used to form the green body. In turn, the model is used to assess dimensional precision goals with respect to component uniformity and practical process controls and even computer simulation tools. Rand German (rmg4@psu.edu).

Including Strength (cont.)

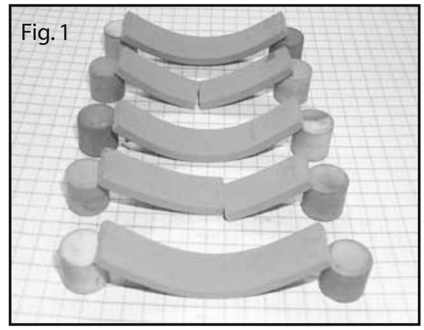


Fig. 1

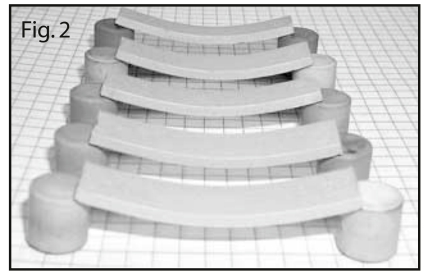


Fig. 2

Figure 1 shows beams that have not been presintered, while Figure 2 shows beams that have been presintered. Both experiments experienced the same sintering conditions after being placed on supports. The presintered samples only deflect a small amount under their own weight during sintering, while the samples that have not been presintered fail during sintering. It is clear that presintering, which did not cause any shrinkage or densification of the powder component, did give the component additional strength to resist excessive distortion during sintering.

The purpose of Debby's thesis is to include the influence of *in situ* strength in the constitutive laws of sintering that govern the sintering model used in the finite element codes. The modified model is tested by simulating the bending beam experiments. A preliminary simulation result, showing the excessive deflection that is predicted by the unmodified model, is shown in Figure 3. Copies of this thesis will soon be available to member companies. Debby Blaine (dcb193@psu.edu).

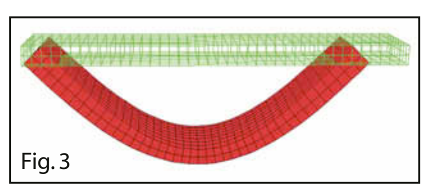
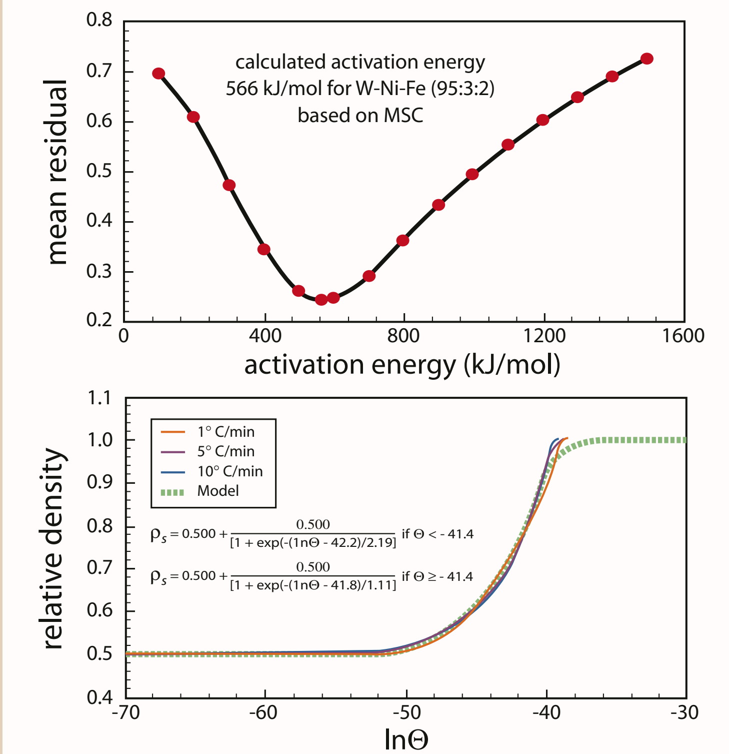


Fig. 3

Applications for Master Sintering Curve: Ni, 17-4 PH, W-Ni-Fe

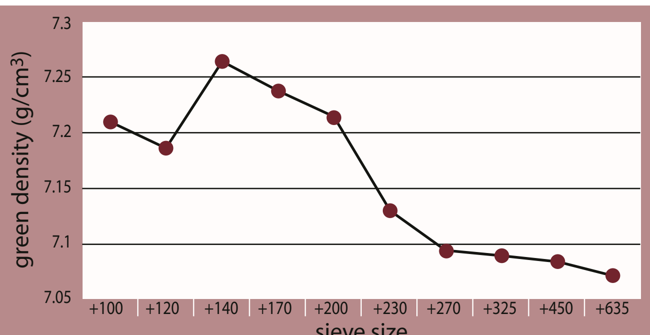
CISP has developed a systematic procedure for the development of a master sintering curve (MSC) and its applications, originally proposed by Lynn Johnson, Northwestern University professor and keynote speaker at Sintering 2003. Materials analyzed include nickel, 17-4PH stainless steel and tungsten heavy alloy. The applications include: (1) to obtain sintering activation energy, which is a very important material parameter to predict the sintering behavior of a given sintering system, by using the mean residual concept; (2) to optimize the sintering cycle by combining thermal analysis and master sintering curve for a given sintering system; and (3) to control the final sintered density properly to a specified application for a given sintering system by curve fitting with the sigmoid function. Contacts: Pavan Suri (pavans@psu.edu), Seong Jin Park (sup13@psu.edu), Debby Blaine (dcb193@psu.edu) and Rand German (rmg4@psu.edu).



High Density Iron Compaction

Achieving near-full-density iron-based P/M materials in a single compaction operation has long been a topic of interest. This study aims to characterize the factors which limit compacted densities in order to generate data useful for the design of high-density systems. The project will seek to model the deformation of individual particles under various strain rates, temperatures, and repetitive loading conditions. Monosized and multi-modal powder mixtures will be considered. These models will be tested by measuring stress-strain relationships of powders during compaction in an MTS hydraulic fatigue tester capable of variable strain rates and repetitive loading. To date, two powders, water atomized Fe and Fe-0.85Mo, have been sieved into particle size fractions and tested for compressibility, flow, apparent density, and tap density. The results indicate an increase in compressibility with increasing particle size despite corresponding decreases in apparent and tap densities. This is due in part to faster work hardening in a smaller particle, since dislocations do not have as far to travel in a small particle before becoming entangled. Increased oxygen content in smaller particles also affects compressibility. The MTS machine is being outfitted with a die set and evaluated for strain rate capability and stress-strain data collection. Neal Myers (nsm104@psu.edu).

Green density vs. sieve size in pure iron at 40 TSI



Partnership with Oregon State University

Sundar V. Atre (formerly Director of Polymer Chemistry at CISP) has recently been appointed Associate Prof. in Manufacturing at Oregon State University and Adjunct Professor at Penn State. He will be working with the Center for Multiscale Materials and Devices (MMD), established by the State of Oregon in collaboration with Pacific Northwest National Laboratory, and industry to develop a new generation of miniaturization technologies for energy, biological, chemical and electronic systems. Hewlett-Packard has donated a building to house the MMD research and outreach activities in Corvallis, Oregon. Sintered materials will play a crucial role in many applications resulting in a broad spectrum of new markets for the industry in the future. CISP and MMD will be working collaboratively to best tap into these opportunities. E-mail: Sundar.Atre@oregonstate.edu Phone: (541)737-8272

Wally Remembered - March 2, 1916–May 15, 2003

O.W. "Wally" Reen started his distinguished career in P/M with Crucible Steel in 1939. He received a PhD from Rensselaer Polytechnic Institute in Troy, NY in 1953. He was an instructor at Purdue University, a research associate at RPI and a metallurgist and research associate at Allegheny Ludlum Steel, retiring in 1980.

Wally joined Intech P/M Stainless Inc. in Ridgway, Pa in 1985 (its first year of business) as Technical Director and was actively involved with Intech until his death. He held approximately 20 patents and developed numerous materials including stainless, tool and ferromagnetic steels. Wally proved instrumental to the success of Intech P/M Stainless by developing additional stainless and full dense 316 SS alloys with superior corrosion resistance with properties comparable to wrought. This led Intech into a niche market specializing exclusively in the manufacturing of stainless steel components.

Wally will be greatly missed at the CISP Industry Member Meetings and by everyone in the P/M industry, especially by those who were fortunate enough to work closely with him.

Student's Corner

John D. Gurosik

John "J.D." Gurosik is a masters student in Engineering Science graduating in December 2003. J.D. has worked at CISP for over three years while completing his B.S. in Mechanical Engineering and continued through a master's degree. His current research focuses on the evaluation of processing conditions for pure molybdenum components. J.D. is from St Marys, PA and is interested in continuing to work in the field of powder metallurgy after graduation. Contact J.D. at jdg188@psu.edu.

CISP Offers On-site Training

CISP encourages "education throughout life" by offering industry personnel an opportunity to receive on-site training. This allows a company the benefit of training several individuals at one time without the additional expense of travel, hotel costs, etc. CISP has several refined, high-quality short courses and seminars ready for presentation. They can be customized to meet the needs and specialties of a company. For information on scheduling contact Sharon Elder at cisp@psu.edu.

- Computer Modeling of Sintered Material Processes
- Fracture and Failure Analysis in PM
- Hard and Refractory Metals
- Introduction to Ceramics and Ceramic Engineering
- Introduction to Powder Metallurgy
- Liquid Phase Sintering
- Particulate Composites
- Powder Characterization
- Powder Metallurgy of Iron and Steel
- Sintering Concepts – Theory to Application

Particle Test Request

The most frequently requested service test is particle sizing. Our particle size instruments report particle size distributions, including both the average size and the width of the distribution, and how much powder is present at the size of interest. Repeatability, precision, and resolution are better than with sieve analysis. The test is useful for comparing powders lot to lot, verifying your supplier's consistency, troubleshooting production problems, and for powder producers who need to check that their product matches specifications.

Mercury porosimetry is in heavy demand for giving pore size distribution information. Horiba Instruments placed low- and high-pressure instruments in the CISP lab. Together, they measure a pore size diameter ranging from 0.003 to 125 μm, using a maximum pressure of 60,000 psi (400 MPa). Filters, barriers, concrete samples, and multi-layered ceramic parts are currently being investigated.

Mechanical testing, toll sintering and metallography are also in demand. Metallography is often requested to find the cause of sintering or forming defects on parts, or to identify potential problems from small changes in processing conditions. Fracture surface examination by SEM has been used to find the cause of part failure both after field service and secondary machining and assembly operations. If you have samples for testing, contact Lou Campbell at (814) 865-1393 or lgc102@psu.edu. To view the price list visit our website at *www.cisp.psu.edu*.

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