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CISP Center for Innovative Sintered Products

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PIM Quick Guide

Randall M. German-Center Director

How do you know a good candidate for powder injection molding (PIM)? It is a waste of resources to investigate poor candidates, so a quick means to screen components for early identification of successes is valuable.

As a first pass, consider the schematic decision tree shown in Figure 1. One thing to consider is the annual production quantity. Powder injection molding has historically best matched with industrial needs at production quantities from 5,000 per year on up to 100 million per year. These parts range from specialty firearm sights to cellular telephone vibrator weights. If the target production rates are in that range, then it is appropriate to continue with consideration of PIM.

The next factor relates to the engineering specification. Powder injection molding works best where there are at least 10 specifications (dimensions, locations, surface finish, and such) on the engineering drawing or definition. But the process struggles when the complexity and constrictions exceeds more than 100 call outs. Further, it struggles when tolerances become too tight (0.1%) on more than a few dimensions. Yes, components are in production by PIM outside this window, but they are the exceptions. For example, one crash avoidance sensor mount for luxury automobiles is in production using PIM with 130 dimensional specifications. In other cases, critical dimensions are machined after sintering.

Next is consideration of the materials. It is most important the material is available as a small powder and that powder is easily sintered. Many, but not all, of the common engineering materials are available as small powders, but the powders are more expensive than bulk materials. Since the small powders used in PIM are expensive, good candidates for powder injection molding have high component manufacturing costs when compared to the material cost. A survey across the industry shows that up to 40% of the manufacturing cost is powder.

If a small powder is available, typically smaller than 20µm, then sintering becomes the next concern. In many cases small powders can be sinter densified without extraordinary processing cycles, but many require compositional shifts for easier sintering. For ceramics, this usually means small concentrations of additives to enhance sintering. A common example is the addition of 0.1% magnesia (MgO) to alumina (Al_2O_3).

For metals, sinterability usually means the powders have low contents of ingredients that prove reactive, especially the strong oxide formers, reactive metals, volatile elements, and toxic materials. This usually means PIM compositions avoid beryllium (toxic and easily oxidized), mercury (toxic and volatile), lead (toxic and volatile), manganese (strong oxide former and both the metal and oxide are volatile), zinc (volatile), sodium (reactive), and magnesium (reactive and strong oxide former), aluminum (strong oxide former), tantalum (reactive), diamond (unstable during sintering), oxides of metals such as indium and tin (unstable during sintering), and titanium (reactive and strong oxide former). This is not to say these are impossible to process by PIM, since several have been processed successfully. However, the problems that arise with these ingredients are usually best avoided using more inert compositions.

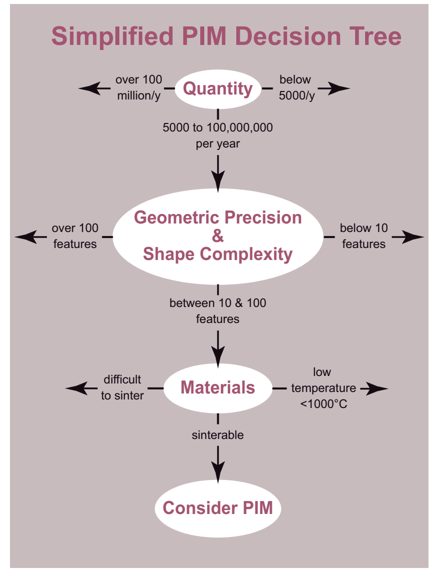


Fig. 1 - How to perform a first screening of candidate components with respect to matches with powder injection molding.

continued on page 2

Upcoming Events

April 17-18, 2002
Metallography
Microstructural Analysis
University Park, PA

April 29-30 2002
PIM Tutorial
University Park, PA

May 13-14 2002
Understanding
Binders & Lubricants
Baden bei Wein, Austria

August 2002 - TBD
Fundamentals of
Powder Compaction
Ridgway, PA

October 9-10, 2002
Industry Member Meeting
University Park, PA

PIM Quick Guide cont.

Another problem is with lower melting temperature materials, where other technologies are very effective. Generally, materials that melt at temperatures over 1000°C (1832°F) are more successful by PIM. One reason for this is that lower melting materials prove easier to process using die casting, machining, or other fabrication routes where there is adequate tooling for low temperature forming. But as the melting temperature increases, then problems with technologies geared to lower temperature materials increase, creating more interest in PIM. Consequently, even though PIM aluminum (melting temperature of 660°C or 1220°F) and other lower melting temperature alloys, such as brass, have been demonstrated, they still are not commercially successful.

If all of these simple tests are passed, then probably the component is a candidate for PIM - except for the final barrier; how much does it cost? In simple terms, the application dictates how much can be paid for a component - it is widely recognized that consumer products tend to migrate toward the low cost of plastics, while PIM is a favorite for higher performance metallic and ceramic products for use in medical or dental devices, defense and aerospace systems, sporting goods, appliance and industrial components, hand tools, business machines, watches, sensors, cutting tools, automotive engines, electronic packaging, or marine equipment. These applications share attributes of requiring good performance, as measured by resistance to high service stresses, wear, corrosion, high temperatures, while possessing good thermal and electrical conductivity, high density, or excellent magnetic response.

Although these criteria might seem constrictive, PIM has succeeded in thousands of applications. As indicated in Figure 2, success comes from the coincidental concerns over shape complexity, production quantities, and performance. To help realize the applications, this Venn diagram indicates some PIM applications that intersect with each of these areas. In addition, surface finish and final properties are often cited as reasons for using PIM. Hard materials prove difficult and expensive to grind or machine, so applications that require materials with poor machinability or applications that require difficult to machine geometries are better candidates for PIM.

Other factors that impact on identification of good candidates include tolerances and surface finish. For rough surfaces, the machining cost is dominated by set-up, but for smooth surfaces machining costs associated with the longer time of machining dominate, as illustrated in Figure 3. Thus, from the perspective of machinability, the following attributes provide an incentive to use PIM:

- designs that require hard materials
- designs that seek good, but not polished surface finishes
- materials that resist machining
- mixed phase microstructures
- component designs that hinder coolant access during machining
- component designs that would require considerable mass removal in machining.

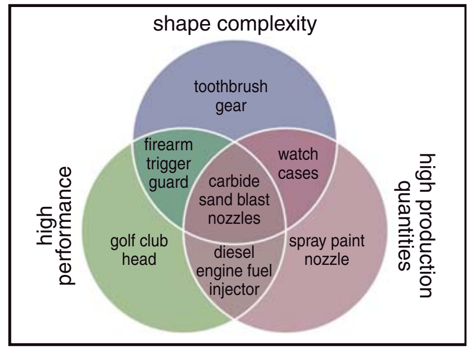


Fig. 2 - A Venn diagram suggesting some of the current justifications for PIM based on high production quantities, high performance, and shape complexity, with various PIM products shown in each of the intersections with these three concerns. Cemented carbide sand blast nozzles and water jet cutting nozzles or other wear resistant complex shapes are an idealized convergence of these three concerns.

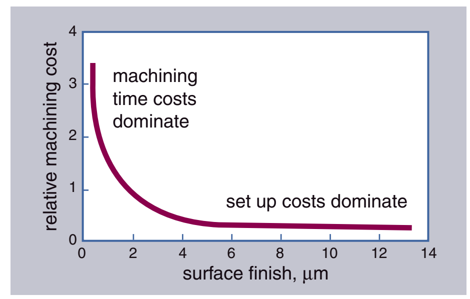


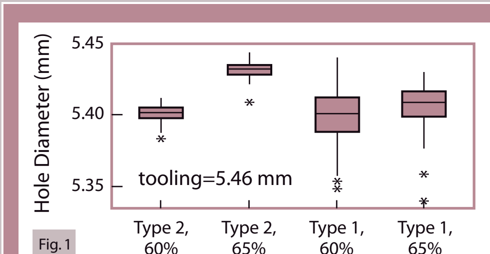
Fig. 3 - Machining is relatively inexpensive for rough surfaces and set-up dominates cost, while for smooth surfaces cost is dominated by the machining time. For PIM to compete against machining, it is important to seek smooth surfaces and situations where there is considerable mass removal needed to generate the final shape concerns.

Today, most common engineering materials are available via PIM. Although a wide range of materials can be processed, in the end a few dominate the field because of widespread use and low raw material cost:

- ferrous alloys
  (steel, stainless steel, and tool steel)
- oxide ceramics
  (silica, alumina-based ceramics, zirconia).

For these materials, there is an ample supply of powders, the powder cost is relatively low, and sintering is well established for these materials.

Good Results in Dimensional Behavior of Green MIM Components



Feedstock	Percent Shrinkage		Percent Variation	
	Core Hole	Length	Core Hole	Length
Type 1, 60 vol %	1.12	0.90	0.33	0.05
Type 1, 65 vol %	0.99	0.50	0.28	0.04
Type 2, 60 vol %	1.08	0.70	0.11	0.02
Type 2, 65 vol %	0.54	0.35	0.10	0.01

Recent development work at CISP on the dimensional behavior of MIM components has produced some interesting results. Shrinkage of the green components is found to range between 0.5 and 1.3 %, after being removed from the mold. The shrinkage and the variability of the green components are related to the powder loading and the powder type. As the powder loading increases, the shrinkage out of the mold decreases. Also, the variability in dimensions is strongly related to the powder type and weakly related to the powder loading. An anisotropic shrinkage behavior has been quantified. Inner cores have greater shrinkage than the overall length of a component. These findings are illustrated in the following table and figure. Note that Type 1 is –22 µm gas atomized powder and Type 2 is –22 µm water atomized powder. Contact: Donald Heaney at dfh@psu.edu or Rudolf Zauner at rcz1@psu.edu

Fig 1 - The effect of powder type and solids loading on the green dimensions of a MIM coponent.

Table : Green shrinkage and dimensional varibility as a function of powder type and powder loading

Full Steam Ahead

CISP recently received a grant of $1 million from the Pennsylvania Technology Investment Authority for our third year of funding. We plan to couple this with an additional $500,000 from industry supporters. As in year 2, roughly 56% of these combined funds will be used to support pre-competitive projects. We have coupled new and continuing projects to give CISP a broad portfolio. We are now in the final stages of mapping out the research portfolio for the upcoming year. It is anticipated that 10 to 12 projects will round out our research program beginning 1 July 2002. To find out how to mentor or participate in this effort contact Sharon Elder: cisp@psu.edu

Proposed Research Projects for Year 3

- Practical Aspects of Powder Metal Lubricants*
- Numerical Simulation of Binder Burnout and Stress Formation*
- Sintering Process Simulation for Dimensional Control
- Spark Plasma Sintering of Nanograin Size Carbide Composites for Tribological Applications
- Dimensional Control of Stainless Steels
- Multiple Axis In Situ Monitoring of Dimensional Changes in Debinding, Delubrication, Sintering, and Heat Treatment
- Qualification of High Strength P/M Alloys
- Exploration of Net-shaping and Different Consolidation Techniques for Refractory Metals (RM)*
- Process Enhancements for Powder Injection Molding for Six Sigma Precision
- Ultrasonic Sensors for "In-situ" Monitoring of the Sintering Process
- Characterization and Control of Defects in Die Compacted Green Bodies
- Crack Detection in Green Compacts*
- Dimensional Producibility of High Precision Sintered Components

*denotes new project

The Passsing of the Torch

The spring Industry Member Meeting was held on 25-26 February 2002 at the Penn Stater Conference Center, University Park, PA. Over 100 people attended the two-day meeting including faculty, students and 56 representatives from organizations and industry. Updates on current research projects, educational initiatives, poster session, and an industry panel discussion rounded out the event. Dr. Naresh Thadhani, Professor from Georgia Tech provided insights on "Dynamic Compaction of Metal Powders: A Historical Perspective, Barriers, Successes, & Opportunities".

Council Members

Pictured left to right:
John Frey (Air Products)
Mike Laing (CM Furnaces)
Mark Greenfield (Kennametal)
Chi Leong (AMI Doduco)
Ulf Engström (North American Höganäs)
Dean David Wormley (PSU Executive Council Chairman)

The Industry/Executive Council met immediately following the regular meeting. The key issue for the Council was the balance and awarding of research projects slated to begin on 1 July 2002. CISP recognizes the Council members that have faithfully served for the past two years:

Robert Balliett (H.C. Starck), Clifford Bampton (Boeing), Dan Carroll (OMG), William Clark (St Marys High School), Santosh Das (Honeywell), Zhigang Fang (Smith Tool), John Frey (Air Products and Chemicals), Mark Greenfield (Kennametal), Bob Howard (Clarion Sintered), Young Rae Jang (DSI), Claus Joens (Elnik), George Jucha (AMETEK), Edward Kimmel (Osram Sylvania), Anand Lal (Motorola), Chi Leung (AMI Dudco), Deepak Madan (F.W. Winter), Owe Mårs (NA Höganäs), Kevin McAlea (DTM Corp), K.S. Narasimhan (Hoeganaes), Jim Neill (CM Furnaces), Carlo Pantano(PSU), Michael Pohl (Horiba), Vic Russo (Ben Franklin Technology), Donald Smith (HAWK), Tim Smith (Cont. Metal Tech), Donald White (MPIF), and Dean David Wormley, (PSU Chairman)

At the October 2001 meeting the Executive Council voted to combine the 2 Councils into one. New Council members for 2002-2004 are:

Robert Balliett (H.C. Starck), William Clark (St. Marys Area High School), Ulf Engström (North America Höganäs), John Frey (Air Products), Mark Greenfield (Kennametal), Anthony Griffo (Smith International), Dan Henkel (Pall), John Kosco (Keystone Powdered Metal), Jack Krajcirk (Dorst America), Young-Sam Kwon, (CetaTech), Deepak Madan (F.W. Winter), Kevin McALea (DTM), K.S. Narasimhan (Hoeganaes), Jim Neill (CM Furnace), Thomas Patrician (Osram Sylvania), Michael Pohl (Horiba), Richard Seymour (KYK), and Donald White (MPIF)

New Tool for Numerical Modeling

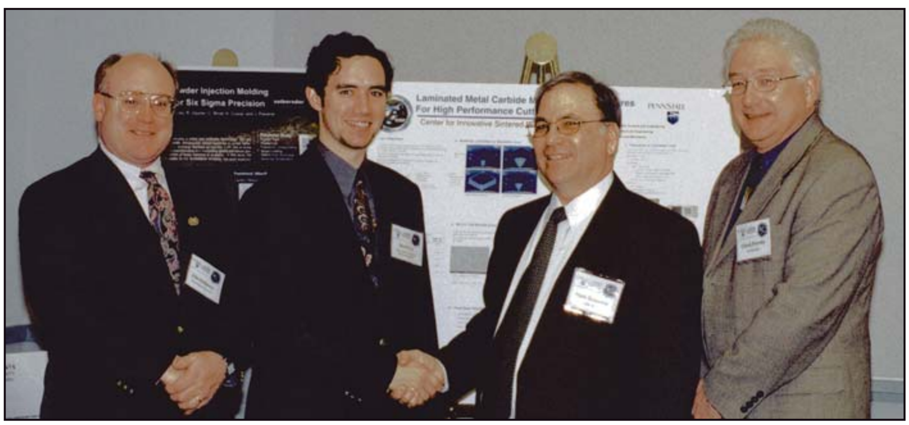
New capabilities to model powder metallurgical processes are being organized in CISP. There have been continuous efforts to better understand all process steps through the application of numerical modeling. Powder compaction, injection molding and sintering are only a few examples that are being simulated using numerical techniques. To add to the expertise CISP has recently acquired FIDAP from FLUENT Inc. This software is a finite element package designed to calculate fluid flow, heat transfer and mass transfer. This powerful tool will be used to model phenomena such as lubricant burnout debinding, liquid phase sintering, and powder coating techniques. The capabilities of the software will give insight into our experimentation and allow optimization of the atmosphere and its flow, as well as guiding selection of furnaces and mixers, and improving their use in terms of efficiency and planning. Extrapolation of process parameters and prediction of consolidation behavior for novel materials can be a cost factor and time compressing measure. Reducing time from design to market, one can gain a competitive advantage. Contact: Chantal Binet (cub9@psu.edu)

ARCINA Grand Opening

Pictured left to right: Rudi Zauner, ARCiNA, Erich Kny, President ARCiNA, Sharon Elder, CISP, Richard Wiles, Eco. Dev. Coordinator for Congressman Peterson, Gunter Igler, ARCiNA V. P., Heinz Seidl, ARCS

The Austrian Research Center in North America officially springs to life with the grand opening ceremonies at the PennStater Hotel on 11 April 2002. The full day of activities will include special presentations on basic research, applied research and R&D – a global game. The keynote speakers are: Wilhelm Gauster, Deputy Director Physical and Chemical Sciences Center, Sandia National Laboratories and Wolfgang Schmidt, Director of DaimlerChrysler AG, Aeronautics, Defense and Space Research Program. ARCiNA is the North American subsidiary of Austria's largest applied research enterprise. In partnership with CISP, ARCiNA extends the European boundaries by promoting R&D initiatives for small to large industries focused on materials development and processing.

Kennametal Graduate Fellowship Award



Pictured left to right: John Hellmann, PSU, Kevin Fox, PSU, Mark Greenfield and Chuck Petrosky, Kennametal.

Kevin Fox recently received the Kennametal Graduate Fellowship Award. Mr. Fox is a Ph.D. candidate in Materials Science with an emphasis in Ceramic Science and Engineering. His doctoral thesis work applies calendaring and spark plasma sintering techniques to the fabrication of functionally graded WC-Co structures for high-performance cutting tools. For the past 2 years Kevin has been working at CISP on the Laminated Metal Carbide-Metal Binder Structures for High Performance Cutting Tools project, under the direction of Dr. John Hellmann. This award is part of a strategic alliance between Kennametal and Penn State University to enable the two organizations to collaborate in several areas, with particular focus on advancing new metal cutting technologies and manufacturing processes and other areas of mutual interest.

Mutually Beneficial Gains

If you could cut your R&D in half and still be high-tech would you do it? Many companies in sintered materials are low on R&D investment, but their competitors often are more aggressive. Recently I have been considering CISP as a mechanism for leveraging R&D. In examining the DOE industry trends of R&D as a percent of sales, one finds that depending on the industry the percentages range from barely a one-half percent in the primary metals industry to over 11% for pharmaceuticals. This industry falls under the manufacturing average where roughly 3% should be invested to keep competitive. You can either cover the whole bill or get more "bang for the buck" on competitive research. For a very low expenditure on the part of industry, CISP offers the ability to leverage. Our member industries have the opportunity to mentor or implement process improvements from any of the 13 current research projects. This is also an opportunity to distribute risks, minimize fixed costs, increase the opportunity for innovation, reduce costly errors, and use resources effectively. What would motivate someone to create a relationship with competitors? The answer is straightforward - if your competitors and customers are using this leveraging mechanism, perhaps you can't afford not to do the same. According to John Case, INC magazine, global pressures are forcing even the fiercest competitors to do something that all the industrial policy in the world couldn't: cooperate. Thus CISP is providing this industry with a leveraging mechanism where one can see mutual gains benefits as a win-win situation for all involved. Contact Sharon Elder: cisp@psu.edu

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