

ABSTRACTS OF PRESENTATIONS OF THE 2009 INTERNATIONAL CONFERENCE ON POWDER INJECTION MOLDING

North American MIM Status

The North American MIM industry is alive and doing very well. Industry statistics show that sales of MIM products grew steadily over the last few years and optimism is high that further growth will be attained. The MIMA presentation made at October 2008's MPIF Fall Management Conference will be the basis of the presentation.

Matt Bulger

Asian MIM Status

The Asian MIM industry continues to grow through domestic consumption and exports. The market is approximately \$300 million with 10% growth annually. Technologically speaking, advanced MIM corporations in Asia can fully compete with Western corporations, and the high skill level and low labor cost make Asia manufacturing attractive. A review of the Asian MIM industry including Japan, Taiwan, Korea, China, Singapore, Thailand, Malaysia, and India will be presented.

Junichi Hayashi and Yoshiyuki Kato

European MIM Status

The European MIM industry continues to grow with a focus on the automotive industry, currently responsible for over 50% of the European MIM market. Raw material fluctuations continue to impact metalworking processes, favoring MIM's netshape appeal.

Martin Kearns

Effect of Powders and Binders on Rheological Behavior and Molding Parameters in Powder Injection Molding Process

For successful powder injection molding (PIM), this study shows the behavior of related parameters, such as design of the binder system, feedstock formulation, and the details of the component, mold, and processing cycle are essential for optimizing the process. The powder with different combinations of binder systems and the binder system with different combinations of powder were investigated with both experiments and simulations. First, an experimental rheological study has been performed to evaluate the influence of powder/binder combinations on the rheological behavior and thermal stability of various PIM feedstocks. Second, based on the proper characterization of the feedstock, the simulation study revealed the pressure-, temperature-, and velocity-related parameters associated with the selection of powder and binder system. In addition, the database was established up to 400 equations for modeling and simulation with graphs and experimental data to map between materials and their properties based on the material informatics concept.

Seokyoung Ahn, Shiwoo Lee, Seong Jin Park, Sundar V. Atre and Randall M. German

Developments in Gas Atomized Alloy Metal Powders for MIM Applications

The benefits of Metal Injection Molding (MIM) as a near net shape manufacturing route for complex parts are being realized in an increasing array of alloys and applications. In this presentation, we review overall market activity and trends in application types highlighting growth sectors in particular. Examples are drawn from stainless steels, tool steels, cobalt alloys and nickel base superalloys. The links between starting powder attributes and finished component cost and performance are discussed with reference to key powder characteristics that have enabled the MIM route to demonstrate advantages over conventional metal forming technologies. For critical applications, powder cleanness is increasingly viewed as an important factor affecting mechanical properties and polished appearance and advances in control of cleanness are described.

Martin Kearns and Toby Tingskog

The Effect of Processing Variables on Gas Penetration Depth in Gas-Assisted Powder Injection Molding

A rod-like specimen was molded by means of gas-assisted injection molding on a rapid prototyped epoxy mold. The study of four process variables on the influence of gas penetration depth was explored for polypropylene and stainless steel (SUS316L) feedstock for powder injection molding. The Moldflow 3D Gas-Assist analysis package was used accordingly to understand the effects of shot size on gas penetration depth. Experimental results revealed that gas delay time is the dominant factor affecting gas penetration depth for the polypropylene under investigation. We also observed that the epoxy mold enables a basic experimental setup for this kind of study by reducing the chance of freeze-off due to its lower heat conductivity compared to a conventional mold material. Based on statistical results, optimum process parameters were obtained.

Seokyoung Ahn, Manuel de Hoyos, Kye Hwan Lee, Miguel A. Gonzalez Seong Jin Park

Molybdenum Setter with Ceramics Coating Layer for Sintering and Annealing

Ceramic coated molybdenum setters were developed to be suitable for the sintering of powder injection molded parts made from stainless steel, iron-nickel alloys, tungsten alloys and other such metal alloys. Molybdenum has superior properties when compared to alumina, such as low specific heat (molybdenum: 0.27 J/g K, alumina: 0.80J/g K), high thermal conductivity (molybdenum: 140 W/m K, alumina: 40 W/m K), and excellent bending strength at high temperatures (at 1200 °C, molybdenum: 300 MPa, alumina: 200 MPa). Coated molybdenum setters have a shorter heat cycle, a more uniform temperature distribution, a smaller thickness, and have a stronger shock-resistance when compared with ceramic setters. For sintering of various materials, a variety of suitable ceramic powders can be chosen from, and coated to the molybdenum setter.

Masahiro Katoh and Hiroshi Yoshida

Simulation of Micro-Parts Sintering

The sintering behaviors of fine stainless steel powders have been studied. The Elastoviscoplastic model has been identified. The simulation of the sintering stage has been realized with Abaqus software. The comparisons with experiments have been good agreement with numerical results.

T. Barriere, J. Song, C. Quinard, B.S Liu and J.C. Gelin

MIM of CoCr Based Alloys Suitable for Medical Device Applications

The use of metal injection molding (MIM) has grown considerably in recent years because of its capability to economically produce complex net-shaped parts in a number of engineering alloys. MIM has been particularly successful medical device applications in which stainless steels are the most common MIM alloys used. However increasingly medical applications require improved biocompatibility and MRI compatibility beyond that offered by stainless steels. In those applications CoCr based alloys are desirable and have been used as cast and wrought products with great success. This study will discuss the development of CoCr based MIM alloy systems in the compositions of ASTM F75 and F562. Topics of alloy powder and binder system selection and their effects on feedstock development will be discussed. The effects of key processing parameters such as debinding and sintering conditions will be discussed. The resultant moldability, alloy microstructures, and mechanical properties will be evaluated. This study will also discuss topics related to the commercialization and use of MIM CoCr alloys as equivalent alternatives to the more common cast and wrought versions of the alloys.

J. Alan Sago, Mark W. Broadley and John K. Eckert

Titanium Metal Injection Molding

Powder injection molding of pure Titanium offers an attractive near-net shape fabrication method for complex shaped mechanical components. In practice however Titanium appears to be very sensitive to contaminations at elevated temperatures during debinding and sintering. This study investigates Titanium MIM production. Influences of debinding and sintering conditions on mechanical properties and chemical impurities are discussed. Addressed are thermal binder removal of backbone binders prior to sintering, issues of furnace design as well as influences of sintering atmospheres, sintering temperatures and times. The different process conditions are related to the chemical, mechanical and microstructure behavior of pure Titanium MIM components.

Jochen Eichstädt, Steffen Krug and Stefan Zachmann

Development of Powder Injection Molding Process for Sponge Titanium Alloy

Newly developed sponge titanium (Ti) powder and its alloys have price competitiveness suitable for automotive application. In this study, the metal powder injection molding (PIM) process was developed for sponge Ti alloyed with iron (Fe) and zirconium (Zr). The effort included development of the alloy composition, binder system, mixing process, debinding process, and sintering process. All samples were analyzed in term of density, microstructure, and mechanical properties. The process simulation and microstructures analysis were performed to rationalize the effects of processing conditions on the sintered density and mechanical properties. In addition, we compared the results with hydride-dehydride (HDH) Ti alloy.

Seong Jin Park, Ozkan Gulsoy, Pavan Suri, Arockiasamy Antonyraj, Randall M. German and Paul Wang

Debinding Factors for Metal Injection Molding of Grade 2 Titanium

A two component binder system has been utilized for high purity titanium metal injection molding. This paper discusses the molding of small components and a subsequent debinding process which does not leave the residual chemical impurities that impair titanium's performance, particularly for medical applications. Debinding involves chemical removal of the primary ingredient, polyethylene glycol, followed by thermal debinding under vacuum (10⁻³ Pa),

completely removing the secondary (acrylic) component. Chemical debind leaves an open network of pores that allows complete removal of the acrylic binder during thermal debinding. Chemical analysis following thermal debinding shows no increase in oxygen content from the starting titanium powder and very low levels of carbon contamination. Levels of carbon are demonstrated to increase from 0.01wt% to 0.04wt%, well within the ASTM standard for grade 2 commercial purity titanium

Emma Gill, Iain Todd, Chris Hampson and Mike Thomas

Development of Copper Distributor by Powder Injection Molding

Y-shaped copper distributors of refrigerants for air conditioner are required high durability under high internal gas pressure. In this study, 3 different size Y-shaped copper distributors were developed by powder injection molding process. To achieve high mechanical properties of copper PIM parts, several process conditions such as sintering temperature and sintering time were investigated two kinds of copper powder. The mechanical properties of copper tensile samples by PIM were excellent and showed almost the same mechanical properties as commercial annealed copper. The optimum shape of distributor was designed to minimize the size and weight of the distributor and was manufactured by PIM. The leakage tests of Y-shaped copper MIM distributors under internal pressure were successful and numerical simulation by finite element method was performed to verify the reliability of copper MIM distributor under higher internal pressure.

Young-Sam Kwon, Seong-Taek Chung, Seong Jin Park and Randall M. German

From Micromachining to MIM Micro-Parts

Different micro-manufacturing processes such as WEDM, laser ablation and HSM have been used to manufacture micro-die cavity molds. Evaluation of feedstock containing fine stainless steel powders was studied. Samples were molded, debound and sintered without defects, having high mechanical characteristics.

T. Barriere, C. Quinard, G. Michel and J.C. Gelin

Micro MIM Processing of Materials for Medical Applications

Metal Injection Molding (MIM) is already successfully being used for commercial processing of biocompatible materials (316L stainless steel, Co-Cr-based alloys, titanium alloys) for medical devices or implants. Meanwhile Micro-MIM is also gaining importance in this field. In this paper some recent developments in Micro-MIM for medical applications are presented. For instance, pilot scale production of a replica of the smallest human bone (stirrup bone) made of titanium was set up. Microstructure and properties of the sintered parts are assessed towards their suitability as implant materials. Another potential of μ -MIM for medical applications is micro-structuring of metallic surfaces to enhance the bioactivity of implant materials. Molding and sintering routes were developed to obtain repetitive micro surface patterns on 316L stainless steel and titanium. For stainless steel processing, nano powders were used to obtain ultra fine microstructures, leading to superior cell proliferation and differentiation compared to non-structured surfaces.

Philipp Imgrund, Vera Friederici, Frank Petzoldt, Arie Bruinink and Malak Bitar

Zirconia Drill and Burr for Dental Application by PIM

Zirconia is a promising material for dental applications because of its high biocompatibility, structural integrity, and mechanical properties, and low solubility. In this study, high-performance zirconia drill and bur for dental applications were developed by powder injection molding manufacturing process. To achieve high mechanical properties of zirconia PIM parts, several preliminary conditioning processes such as sintering temperature and sintering time were investigated with two kinds of zirconia powder. Also, the effect of hot isostatic pressing on the mechanical properties of sintered zirconia PIM parts was investigated. New zirconia drill and bur were designed to minimize the final grinding of sintered parts and were manufactured by PIM. Effect of the final grinding conditions on the performance of zirconia drill and bur was investigated. In vitro tests demonstrated the reliability and efficacy of new zirconia drill and bur for many dental applications.

Young-Sam Kwon, Seong-Taek Chung, InJun Yoon and Seung-Ho Baek

ABSTRACTS OF PRESENTATIONS OF THE WORKSHOP ON MEDICAL APPLICATIONS OF MICRO POWDER INJECTION MOLDING

An Assessment of Technical and Marketing Barriers

The application of powder injection molding to support minimally invasive dental and medical technologies is a potentially massive opportunity. Several efforts are in place to overcome the various problems, and in many cases these are building on progress in other fields, such as nanoscale powder synthesis and microminiature plastic molding. The R&D costs are large, so the barriers of time, personnel, talent, materials, equipment, and designs all must be worked simultaneously. Although a rapid growth area, microminiature PIM must have a sound assessment on the barriers and opportunities and minimally invasive surgery seems to show the largest cost-benefit situation, should enabling technologies be available.

Randall M. German

Dental Applications of Micro Powder Injection Molding

There are many medical applications of powder injection molding such as orthodontic bracket, various surgical instruments including laparoscopic jaws, suturing jaws, needle driver, distal clevis, and many other dental applications. Recently, micro powder injection molding technique has been utilized to replace the conventional method of manufacturing dental instruments such as stainless steel tips for the treatment of dental caries, zirconia ceramic posts for retaining endodontically treated teeth, and zirconia bur for the grinding of damaged or affected tooth structure. In vitro and in vivo tests were performed to verify the capability of new tips and posts and demonstrated the reliability and efficacy of new tips and posts.

Seung-Ho Baek

Tips for Dental Application by Micro PIM

Various type tips are essential part of endodontic treatment and retreatment. In some circumstances, diamond coated tips are widely applied for the treatment of dental caries by grinding the damaged or affected portion of teeth. Diamond coated tips are very useful and have limited durability because diamond particles on the tip are easily separated during dental treatment. In this study, new tips were designed to enhance the grinding performance and durability of tip by forming the very fine projections on the tip surface. Tips with different size of projections on the tip surface were manufactured by micro powder injection molding. The shape of projections on the tip surface was investigated with different size of projections and particle size of powder. In vitro tests demonstrated the longer and more predictable durability and high performance on grinding of damaged and affected tooth structure with the new tips manufactured with the micro PIM process.

Young-Sam Kwon, Seong-Taek Chung, In-Hwan Lee and Seung-Ho Baek

Challenges of Micro-PIM

Large scale production of Micro-PIM parts will require additional developments to insure success. Decreases in the scale of detail of Micro-PIM parts will require work on powders, binders, tool making, molding, and sintering. Production issues that are of moderate concern presently will become of even greater concerns in the production of Micro parts. Examples of present PIM production parts will be used to discuss the challenges to make even smaller parts.

Timothy McCabe

Fabrication of Micro-Components by Micro Powder Injection Molding

Micro-components, such as microstructured parts and micro-parts, have been produced by micro powder injection molding. In the case of microstructured parts, high-aspect-ratio micro-structures have important advantages, such as high sensitivity in sensors. In this presentation, the fabrication of micro-components, especially for high-aspect-ratio micro-structures, will be discussed. Issues associated with the fabrication and how they are overcome will also be highlighted.

N. H. Loh, S. B. Tor, G. Fu, B.Y. Tay, Y. Murakoshi and R. Maeda

Metal and Ceramic Micro Parts Produced by Powder Injection Molding (Micro PIM)

Micro PIM holds a considerable potential for the production of ceramic components. Due to the possibility of large-scale series production it also exhibits a great economic potential.

There are no doubts that geometrical accuracy of the final parts is a crucial matter of PIM which currently achieves tolerances of 0.2 to 0.5%. In case of high precision products, however, replication accuracy has to be improved. Under this respect thorough studies on the dimensional tolerances of zirconia single-mode ferrules have been performed to determine the influence of process parameters on part quality. As a result parts tolerances considerably lower than the usual values of approx. 0.5% have been reached. In certain directions it was possible to reduce tolerances to $\pm 0.1\%$.

To widen the application opportunities of Micro PIM attempts were started to manufacture more complex shaped devices. As a demonstrator a nearly free-formed feed screw for a micro-dispenser unit was chosen. A modified micro injection molding process was inaugurated: usually, such screws are manufactured in tools containing two or more clamping units to release the cut-back geometry of the screw. However, the occasion of burrs can never be avoided completely so that a novel special spindle construction was developed to unscrew the molded green body before tool opening. Initial trials were carried out with zirconia feedstocks, and debinding and sintering could be carried out without major problems. At present, further miniaturization of samples geometries is performed.

An important purpose of the current R+D work is to extend the Micro PIM technology so as to be able to integrate two ceramic materials with different physical properties, for example different mechanical strengths or electrical resistivities, in a single piece. A further advantage of this so-called Micro-Two-component Injection Molding (2C-MicroPIM) process is the considerable reduction of mounting costs..

An interesting example for 2C-MicroPIM is the creation of gear wheel and shaft components: While the gear wheel was molded using a zirconia feedstock the shaft is made of aluminum oxide ceramic. Investigations to fabricate immobile or mobile ceramic shaft-wheel components have been carried out. The newest results will be presented.

Due to the considerable economic impact it can be expected that 2C-MicroPIM will draw further attention in the future.

V. Piotter, T. Mueller, K. Plewa, A. Ruh, H.-J. Ritzhaupt-Kleissl and J. Hausselt

Lessons to be Learned from Nanostructures Supplied by Nature

I envision my presentation dealing with the small scale biological structures (micro and nano), such as those that generate color (non pigmented). I will integrate how this relates to use of analytical tools of microscopy and microanalysis. Of course, I will attempt to relate all of this ultimately to powder injection molding in order to join into the overall discussion. I will do my best to get an abstract to you by the end of this weekend and would be happy to write a manuscript summarizing key points for inclusion in the workshop proceedings.

Giselle Thibaudeau

Zirconia Post for Dental Application by Micro PIM

A dental post is essential component to retaining an endodontically treated tooth. An increasing demand for esthetic restorations has led to the transition to a tooth-colored post. Zirconia is a promising material for the dental post because of its high biocompatibility, structural integrity, and mechanical properties. Loss of retention is the most common reason for post failures. As a result, retention of a post and the stability of a core restoration are critical components to a successful dental restoration. In this study, new zirconia post was designed to enhance the retentions between post and dentin and between post and core by increasing the surface area of post. This study revealed that increasing the friction between post and dentin or core with a number of fine retentive cones on the post surface increase the retentive features of the post. In vitro tests demonstrated the reliability of new zirconia post with micro powder injection molding technology.

In-Hwan Lee, Hee-Chul Kim, Seung-Ho Baek, Seong-Taek Chung and Young-Sam Kwon

Material Homogeneity in Ceramic Microarrays

Shrinking component sizes tax our fabrication abilities. In powder systems, the rule of thumb is that the powder size must be smaller than 5% of the feature dimension to reduce wall effects. Features of 1 μm size require particles below 50 nm. While micromolding with polymers has met with some success, material homogeneity is a critical in PIM because it results in various molding defects in metal or ceramic microparts. Material heterogeneity, or inhomogeneous nanoparticle density distribution, in green parts is related to inhomogeneous feedstock mixtures as well as powder/binder separation occurring in melt flow. The issue becomes more prominent for micro PIM because of the small particle sizes and fast mold flow velocity for filling. Small and irregular-shaped particles tend to form agglomerates in feedstock mixture. The fast mold filling may cause more particles to migrate because of the increased shear rate gradient in cavity. These issues lead to some strong interests in studying the influence of powder attributes in the evolution of homogeneity problems in microparts such as microchannel arrays. The present work is focused on understanding the origin and evolution of homogeneity issues during the processing of nanoscale powders into miniaturized features using PIM.

Sundar V. Atre, Sachin Laddha, Carl Wu, Shiwoo Lee, Kevin Simmons, Seong-Jin Park and Randall M. German

Bioceramics, Biophotonics, and the Potential for Micro PIM Fabrication of Medical Devices

Engineered ceramics have been serious candidates for applications in orthopaedic medicine for more than a century. These inherently brittle bioceramics have had a shorter history and more limited applications in comparison to ductile metallic and polymeric materials. This limitation is offset by the fact that a ceramic, hydroxyapatite (HA), is the primary mineral content of bone. Near-theoretical densities of nano-scale HA can be achieved in minutes by the field-assisted sintering technique (FAST). The benefits of Micro PIM will also be discussed in regard to specific device design concepts. Dental applications of bioceramics are also attractive due to the same chemical similarity to natural materials, as well as a predominance of compressive loads for which ceramics provide optimal mechanical performance. Finally, the discussion of device design concepts will be broadened to include efforts at the NSF-funded Center for Biophotonics Science and Technology (CBST), headquartered at UC Davis.

James F. Shackelford

Advanced PIM Process of Ti-6Al-7Nb Materials for Medical Application

Ti-6Al-7Nb alloy has been developed for more suitable biomaterial in place of Ti-6Al-4V alloy, because the vanadium is toxic to human body. In this study, the powder injection molding process was applied to produce the Ti-6Al-7Nb alloy compacts using alloy powder. For comparison, not

only a alloy powder but also the mixed elemental powders of Ti, Al and Nb, and pre-alloyed powders of Ti-Al and Al-Nb were also investigated. The effects of sintering conditions on the microstructures, relative density and mechanical properties of injection molded compacts were investigated. Sintered compacts using alloy powder showed relatively higher mechanical properties than the compacts using various mixed powders. Eventually, the compacts using alloy powder were improved to be 900MPa of tensile strength with 15% of elongation, which are similar to the properties of wrought materials.

Hideshi Miura, Toshiko Osada, Yoshinori Itoh, Makoto Fujita and Nobuhiro Arimoto

Refractory Metal Powders for Micro-Powder Injection Molding

Refractory metals, especially tungsten, are commonly used for electrodes and counterweights. New medical devices will require micro-sized parts to perform these functions. Sub-micrometer refractory metal powders can be produced from standard chemical processes, but present challenges for mixing and molding. Methods are emerging for producing nanoscale refractory metal powders, which are even more difficult to mix and mold, and present additional challenges with handling prior to mixing and with consolidation. The current state of the art will be reviewed along with prospects for overcoming these barriers.

John L. Johnson

Mixing of Nanoscale Powders and Polymers for Micro-Powder Injection Molding: Simulation Study

For a successful mass-production of ceramic or metallic micro-medical devices, we need to overcome several technological barriers. In this research, we study chaotic mixing of nano particles with a polymer-based binder system in Kenics mixer to get a homogeneous feedstock. By employing the finite element method with the particle tracking method, given distributions of particles along the down-channel direction, a measure of the information entropy are used to quantify the progress of mixing. The sensitivity study shows the influence of the processing conditions on homogeneity of mixing.

Tae Gon Kang, Seokyoung Ahn, Sundar V. Atre, Seong Jin Park and Randall M. German

R&D Activities for Micro-Mold System in KITECH

Recently, products with micro-pattern are widely used in many fields, especially in optical products (IT) and disposable point-of-care bio-chips(BT). With this in mind, KITECH(Korea Institute of Industrial Technology) and Government of Korea initiated national 4-year project for the development of 'micro-mold system', with three fields, i.e. (1) optimal mold design for micro-mold system, (2) mold-system for micro-optical products, (3) molding machine development of rapid thermal pressing for micro-pattern products. In this talk, main results of the 'micro-mold system' project will be presented. Additionally, the direction of scientific programs (mainly on fields of micro-pattern mold) and the current situations of micro-mold related industries in Korea also will be touched.

JeongJin Kang, Chul Jin Hwang and Jong-Deok Kim

Equipment Challenges for Micro PIM

Micro Powder Injection Molding is a fast growing field and pushes the molding machines to the limits. Besides standard powder injection molding also other process technologies like injection coining, variotherm and evacuation used. The equipment (machine, mold and peripherals) will be described and examples with their features shown. Focus on the machine is the injection unit but also required special features of the clamping unit and take out devices are described. On the

mold the challenges are to manufacture with extreme precision, but also to design the mold so that it is suitable for robot take out. One more section covered is the feedstock and its required properties for Micro Powder Injection Molding.

Uwe Haupt

Dimensional Control/Defect Formation Problems and Solutions Related to Debinding and Sintering

Dimensional control problems, including defect formation and distortion, have become important issues in the PIM industry due to the large amount of binder in the PIM components. Debinding and sintering related issues, such as swelling, blistering, or cracking during solvent and thermal debinding and distortion during sintering, particularly when liquid phase sintering is involved, will be addressed. The fundamental understandings of these problems, root causes, and solutions will be presented and discussed with examples.

Kuen-Shyang Hwang

Nanosize Powder Sintering: Modeling Concepts

Sintering of nanoscale powders, which can be used for the fabrication of miniature dental and medical devices, presents considerable challenges. The sinterability of the nanosize powders is usually significantly reduced due to the specifics of the particle nanostructure as well as particle agglomeration. The developed modeling concepts enable the prediction and the optimization of nanosize powder densification during sintering. Kinetics of sintering during consolidation is estimated through a direct numerical analysis of the matter redistribution by diffusion around a single neck between identical spherical particles. Type of packing is introduced into the model through the definition of the packing angle and a special symmetry boundary condition for diffusion fluxes. The numerical analysis of sintering parameters for a single neck allows the evaluation of macroscopic viscosities of the material for different types of the particle packing and enables the estimation of the densification rate of agglomerates and non-agglomerated elements of powder compacts.

Eugene A. Olevsky

Consolidation of Nanoscale Powders by Nanopowder Agglomerate Sintering (NAS)

In the process of sintering of nanoscale powders, the agglomeration of nanopowder leads to inhomogeneous porosity in a green compact, as a consequence, forming gross voids after sintering. A difficult-to-sinter bimodal pore distribution, which is due to the coexistence of intra- and inter-agglomerate pores, led to incomplete densification. Recently, we have suggested a new sintering process for consolidation of nanoscale powders, named by Nanopowder Agglomerate Sintering (NAS) process. The most important idea of NAS process is the optimization of structure design and full density processing of agglomerated nanopowder to fabricate either 2-dimensional or 3-dimensional microcomponents using powder technology. In this presentation, the concept of a NAS process is introduced in association with the role of powder interfaces in microstructural development and densification behavior during pressureless sintering of agglomerated nanopowders. Also the importance of NAS process to the consolidation of nanopowders is discussed based on the results of several case studies.

Jai-Sung Lee, Berm-Ha Cha and Woo-Kyung You

Granularity Issues in Computer Simulations Supporting Micro-PIM

The smaller feature size in micro powder injection molding (PIM) demands a smaller particle, which results in many granularity issues, such as mixing homogeneity of powder-binder mixture, shear-induced powder-binder separation during injection molding, decomposed gas flow during debinding, and component spheroidization during sintering. In this study, we reviewed the state-of-art modeling and simulation for micro-PIM on these regards. Discrete element method (DEM), which can manipulate individual particles, was the focus as the most significant contributor with support from the other numerical techniques such as the finite element method (FEM), surface evolver, and atomistic simulation. Some simulation examples will be demonstrated.

Seong Jin Park, Seokyoung Ahn, Tae Gon Kang, Seong-Taek Chung, Seong-Gon Kim, Seongjai Kim, Sundar V Atre and Randall M. German

Seong Jin Park

Atomistic Simulations of Nanoparticle Sintering

Atomistic simulations are used to probe the sintering process of nanoscale tungsten particles. The primary objective of this study is to understand the fundamental characteristics of atomic movement during sintering and how various additives influence the sintering process. I will present the result on densification and grain growth during sintering as a function of the crystalline misalignment between particles. Pressure assisted sintering is a well-known method to enhance densification by increasing the contact pressure of particles and thus the driving force for sintering, compared to pressureless solid state sintering. The effect of pressure is even more important for sintering of nano scale particles. I will compare the results of simulations with and without pressure during sintering. The presentation will focus on particle deformation before sintering, material softening at elevated temperatures, temperature and pressure sensitivities, and particle size effect. These findings can provide a foundation for a new virtual approach to nanoscale processing and material design.

Seong-Gon Kim, Amitava Moitra, Sungho Kim, Seong Jin Park, Randall M. German