

ABSTRACTS OF PRESENTATIONS AT MIM2010 (TENTATIVE)

North American MIM Status

Matthew Bulger

The North American MIM industry is alive and 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 president will review results of the association's annual survey.

Metal Powder Injection Molding of Various Titanium Compositions

Randall M. German, FAPMI

Titanium supplies are constantly changing and several new options in titanium powder production have recently emerged. These include low-cost recycle materials, virgin products with difficult rheological attributes, and several spherical powder products with high purity and good sintering. Accordingly, the latent ability to perform PIM/MIM with titanium is under re-examination. The efforts include projects on commercially pure grades, alloys, and intermetallics (aluminides and NiTi shape memory alloys). A short history of the field is used to provide perspective. A new aluminum-niobium alloy is the leading composition for medical applications, but for aerospace and industrial uses the aluminum-vanadium (Ti-6-4) composition is still popular. It has long been the contention of this author that PIM Ti is not new, simply the low level of commercial activity is because of economics. Along these lines, market statistics, technology trends, and other factors will be reviewed to show the opportunities. The medical and dental fields are clear winners and the microminiature devices are some of the early targets. Current development activities along these lines will be addressed in this presentation.

Oxygen Sources and Control in Titanium PIM Process

E.Baril, L.P.Lefebvre, Y.Thomas

The effect of interstitials on the yield strength, elongation, hardness and fatigue properties has been widely reported for dense titanium and titanium alloys. Nitrogen has generally the most significant effect followed by oxygen and carbon. While nitrogen and carbon are usually not found at high concentrations in dense titanium, oxygen is a common contaminant due to the high affinity of titanium for oxygen and the high solubility of oxygen in titanium. Titanium powders are currently used for the production of dense and porous components using different processes such as compaction, cold or hot isostatic pressing, powder injection molding (PIM) as well as innovative foaming processes. The initial powder characteristics (surface area), the process parameters (time, temperature) and environment (atmosphere, binder, support) may have a significant impact on the component final oxygen content. It is, therefore, important to identify and control the various sources of oxygen. This paper reviews the sources of oxygen contamination when processing titanium powders. The effect of oxygen will be discussed using experimental results in a Ti-PIM context.

Effect of Additives on Sintering Response of Titanium by Powder Injection Molding

Antonryaj Arockiasamy, Brandon Adcock, Donald F. Heaney, Paul Wang and Mark F. Horstemeyer

Powder injection molding is a newer technology which is highly useful for the production of complex metallic and non-metallic parts of various sizes. Considering the advantageous properties of titanium in automotive applications, components manufactured from low cost sponge titanium powder are more economical. This paper describes the preparation of Ti compacts with and without addition of additives, zirconium and iron, using the powder injection molding (PIM) process. Differential scanning calorimetry (DSC) was used to optimize the sintering cycle. The samples were sintered at 1,275°C and 1,300°C in a high vacuum furnace for hold times of one hour and two hours. The performances of the compacts were studied using tensile testing, hardness testing, and scanning electron microscopy (SEM). The strengths and weaknesses of the test conditions have been analyzed from the densification behavior, microstructure, and mechanical properties.

High-Performance Injection Molded Ti-6Al-4V Alloy Materials added Mo, Fe, Cr

Hideshi Miura, Toshiaki Uematsu and Kenji Sato

Ti and its alloys have been widely used for various industrial and medical applications because of their excellent characteristics of low density, high strength, high corrosion resistance and high biocompatibility. However, it is not easy to produce the complicated shape and precise parts because of their poor workability. Therefore, the advanced powder processing techniques such as Metal Injection Molding (MIM) are hoped to be a suitable technique for fabricating complex shaped Ti or its alloy parts with low cost. In this paper, various high performance Ti alloy materials such as Ti-6Al-4V added Mo or Fe or Cr have been developed by MIM process. The effect of powder type and sintering conditions on the microstructures, relative density and mechanical properties of injection molded compacts were investigated. Also the oxygen and carbon contents were checked in detail for obtaining high performance properties as same as the wrought materials. Eventually, more than 1,000 MPa of strength and 15% of elongation were achieved with MIM process.

Titanium and Titanium–Nickel Parts Processed by PIM of TiH₂–Based Feedstocks

E. Carreño-Morelli and J.-E. Bidaux

Titanium and Titanium-Nickel parts have been processed from titanium hydride and blends of titanium hydride and elementary nickel powders respectively. PIM feedstocks were processed in sigma blade mixers by using binders composed of low density polyethylene, paraffin wax and stearic acid. A two-step debinding process has been used, which consists of solvent debinding in heptane at 50°C (122°F) followed by thermal debinding in a MIM furnace at 500°C (932°F) under argon atmosphere. Dehydrogenation of TiH₂ powder is performed simultaneously with thermal debinding. Titanium parts were sintered at 1,200°C (2,192°F) under argon. The mechanical properties of sintered parts were measured by tensile tests. The microstructure was characterized by optical metallography and scanning electron microscopy. Special care in powder handling, feedstock preparation, debinding and sintering atmospheres, allowed to obtain low residual oxygen, nitrogen and carbon contents, which were determined by quantitative analysis. Watch-bracelet segments were injection molded as test parts, showing good shape preservation and reproducibility. Titanium–nickel shape memory alloys were sintered at 1,200°C (2,192°F) under hydrogen. Differential scanning calorimetry revealed the presence of a reversible martensitic transformation above room temperature. Shape memory effects of more than 4% have been measured.

Manufacturing of Implantable Medical Devices by Metal Injection Molding

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

The use of metal injection molding (MIM) has grown in recent years due to its capability to economically produce complex net-shaped parts in a number of engineering alloy systems. Recent growth of MIM has been particularly successful in medical device markets. MIM has found successful applications in both single use and reusable medical tooling. Stainless steels are the most commonly used alloys in medical applications with 17-4PH and 316 being the most popular. However implantable medical applications require improved biocompatibility and MRI compatibility over stainless steels. In those applications CoCr based and Titanium alloys are desired and have been used as cast and wrought products with great success. In recent years the MIM community has developed MIM CoCr and Ti based alloys to satisfy these applications. This study will discuss recent developments of MIM CoCr and Ti based MIM biomedical alloys for implantable applications. Topics such as alloy powder and binder system selection and the effects on feedstock development will be discussed. The effects of key processing parameters such as for debinding and sintering operations will be discussed. The resultant moldability, alloy microstructures, mechanical properties, and biocompatibility will be presented. The use of secondary post processes such as heat-treatment, HIP, surface finishing, and sterilization processes will be discussed along with their effects on properties and applications. This study will also discuss topics related to the commercialization and use of these implantable MIM alloys in biomedical applications as equivalent alternatives to the more common cast or wrought versions of the alloy.

Cytotoxicity Study on the Titanium Alloy Parts Produced by Metal Injection Molding Technique

R. Ibrahim, M. Azmiruddin, M. Jabir, M. Ridhuan, M. Muhamad, M. Rafiq, N. A. Kasim, and S. Muhamad

Metal Injection Molding (MIM) is a cost-effective technique for producing small, complex, precision parts in high volumes. MIM consists of four main processing steps: mixing, injection molding, debinding and sintering. In the mixing step, the powder titanium alloy (Ti6-Al-4V) medical grade is mixed with a binder system based on palm stearin to form a homogeneous feedstock. The rheological studies of the feedstock have been determined properly in order to success during injection into injection molding machine. After molding, the binder holds the particles in place. The binder systems then have to be removed completely through debinding step. Any contamination of the binder systems will affect the final properties of the parts. During debinding step, solvent extraction debinding has been used to remove partly of the binder systems. The debound part is then sintered at high temperature under control atmosphere furnace. The physical and mechanical properties of the sintered parts then was measured and compared. The sintered parts also then were determined in term of in-vitro cytotoxicity study using mouse fibroblast lines L-929. The results show that the sintered titanium alloy parts produced by MIM fulfill the cyto-biocompatibility test.

Influence of Carbides Reinforcement on the Sintering Process of M2 HSS Feedstock

G. Herranz, R. Alonso, G. Rodríguez.

Metal matrix composites (MMCs) based on M2 HSS (High Speed Steel) and reinforced with VC and Cr₃C₂ carbides were manufactured following a metal injection molding route. The feedstock was prepared with different amounts of VC and Cr₃C₂ carbides to study the influence of each type of reinforcement. The processing steps were discussed and a suitable set of mixing procedure, molding condition and debinding schedule was established. The study of the sintering process was made in high vacuum and nitrogen-hydrogen atmosphere. Density evolution, mechanical measurements and SEM microstructures were used to determine the optimum sintering schedule. The carbides addition allows reducing the sintering temperature. Grain growth and microstructure coarsening were retarded by the effect of the reinforcement. The main consequence was the enlargement of the sintering window. Also the carbides contributed to increase the final hardness.

MIM of 316L Stainless Steel Feedstock and Preparation for Numerical Simulations of Sintering Stage

T. Barriere, X. Kong, and J.C. Gelin

Micro powder injection molding process greatly grows and demonstrates excellent economic prospects in the recent years. Micro-PIM, a technology adapted from PIM, aims to meet the increasing interest in smaller parts and miniaturization. Researches in this area have been developed in our lab by realizing both mono-injection and co-injection experiments with a fine 316L stainless steel powder of 3.4 μm (d₅₀). In this paper, the rheological characteristics of the feedstock were studied. The results show that they are injectable. The processes of mixing, injection, debinding and sintering are reported. Several identifications are also investigated to prepare the numerical simulations of the sintering stage.

Advanced Stainless Steels through PIM Processing

Tim McCabe

Demanding application requirements sometime go beyond what standard MIM material properties can deliver. Engineered alloy solutions achievable through modified processes or development of completely new alloy compositions can often provide the improved properties needed to meet such application performance requirements. Two such approaches have been taken to provide new material properties on two different Stainless Steels. The results of both materials will be presented. The ability of PIM to provide application-specific material properties is an often overlooked manufacturing advantage of the process. Often this advantage can make the difference between successful applications and those that do not make it to production, and can open doors to PIM opportunities that might otherwise not be considered by product design engineers.

Particle-Size Distributions—Effect of Powder Size on Sintering and Part Properties

Toby A. Tingskog, Martin A. Kearns, and Don Whychell

Metal Injection Molding is performed with several sizes of gas-atomized powders. Wider distributions that include larger particles are lower cost due to better utilization of production equipment. Tighter distributions with lower mean and maximum particle size are higher in cost but offer advantages in sintering and part features. The paper explores particle-size distributions from -38 micron to -16 micron. Sintering performance, density, mechanical properties and surface finish are evaluated for 17-4 PH.

The Relationship between Feedstock Solids Loading and Component Distortion in a Production MIM Process

M. Bulger, M. Stucky and H. Zhang

The “critical solids loading” in a MIM feedstock is the maximum volume % of powder in a given powder/binder feedstock system that allows repeatable consistency in molding. Conventional wisdom in MIM holds that a production feedstock must be just below its maximum powder solids loading to be effective; if not the excess of binder in the feedstock will lead to increased distortion as the component moves through the process. In this study MIM components will be produced from feedstocks of differing solids loading. For each solid loading the amount of distortion will be measured at different steps in the process to determine the effect of solids loading on part distortion.

How to Correlate Part Dimensions Using Molding and Sintering Parameters

Philip Corrin, SK Tam, Billy Yim

MIM is the ideal choice for high production tight tolerance parts. Dimension control can be a headache if the important variables aren't understood. This research will thoroughly correlate how small dimension shifts can be achieved by adjusting key processing parameters. We will show that green part density, sintered density, as well as sintered dimensions can be correlated to process changes in molding and sintering. We will correlate to better understand the effects that max sintering temperature and mold packing pressure have on green part density, sintered density, and sintered dimensions. Feedstock pycnometer density, debind cycle, and steel dimensions of the mold will be held constant. We will use an “I-Beam” mold and stainless steel feedstock for our data collection.

Quantifying the Effects of Metal Injection Molding Automation

Deno K. Georgaras

For years, MIM companies have been making sizable capital investments in technology such as robotic automation in an effort to gain a competitive advantage. This paper will quantify the cost and quality advantages gained by automating the metal injection molding process step. Labor costs, production throughput and return on investment data will be presented. Data will be presented illustrating the correlations between injection molding process parameters and product part quality. The paper will also present some challenges MIM companies can expect to face when robotic automation is attempted.

MIM Alloy 718 for Aerospace Components

Jimmy Lu and Richard Fox

Nickel-base alloy Inconel 718 has been widely used in aerospace industry. However, few aerospace parts are made of MIM Alloy 718. This is partially due to the hesitance of MIM suppliers to take on the stringent quality, process, chemical composition, microstructure and mechanical property requirements. This study demonstrates that aerospace grade MIM Alloy 718 meeting all of those requirements can be produced, while possessing room temperature tensile and high cycle fatigue properties which are superior to cast Inco 718 and comparable with wrought Inco 718. To date, small aerospace part satisfying all requirements has been made with MIM Alloy 718 and the process to produce large MIM parts (>1 pound) are in development. MoldFlow computer simulation is being used to aid the tool design and NDT inspection.

Energy-Efficient Powder Injection Molding

Uwe Haupt

Energy consumption has recently become a highly-political, global issue. Economical use of resources is also being increasingly focussed on in the powder injection molding industry. In addition to productivity increases, automation and process expertise, energy efficiency has now become another important factor for maintaining a successful profitable company. Even though the molding process uses only a small portion of the energy in the whole PIM process it is worth while to take a closer look. Every kWh counts. We will show the energy balance of the system machine, mold, thermolator and air conditioning and discuss potential sources for savings. We will also show how to optimally select the most efficient injection unit size.

Recycling of Ferrous Powders by Metal Injection Molding Process

C. Quinard, X. Kong, T. Barriere, J.-C. Gelin, Y. Bienvenu, L. Piezanowski, J. Hugentobler, and , J.-L. Roth

A collaborative project has been developed with the objective to recycle ferrous powders by Powder Injection Molding. The paper is concerned with the way to proceed to get ferrous metallic parts with the required characteristics. The development is well adapted feedstocks based on ferrous powders; the proper injection molding conditions as well as debinding are analyzed, as the resulting physical and mechanical of parts after solid state sintering.

Measurement and Assurance of Temperature Uniformity in a Batch MIM Sintering Furnace

Claus Joens and Satyajit Banerjee

Temperature uniformity in a batch MIM furnace is the key to obtaining MIM parts with repeatable uniform properties. The paper shows how a furnace is checked for temperature uniformity. The furnace incorporates a center thermocouple and AccuTemp, a proprietary temperature correction program that corrects the inaccuracies of the thermocouple reading and displays the corrected actual temperature. This results in a uniform temperature distribution within the furnace. The results of validating a new MIM batch furnace are presented.

Fabrication of Microstructured Parts by Nano-Imprint Lithography Sacrificial Plastic Mold Insert MIM Using Nanoscale Copper Powder

Kazuaki NISHIYABU, Daiki TANABE, Yasuhiro KANOKO, and Shigeo TANAKA

This study aims to develop the manufacturing method of micro-structured parts by the metal powder injection molding (MIM) inserted micro-sacrificial plastic molds which were prepared by nano-imprint lithography (NIL) technique. In this process named NIL/ μ -SPiMIM, the feedstock composed of nanoscale copper powder and polyacetal-based binder was adequately prepared and molded into polymethylmethacrylate films with fine line-scan structures, and it was sintered in a reductive gas atmosphere followed by solvent debinding of the films. The filling rate of feedstock into micro-channels and transcriptional property in sintered parts was evaluated by cross-sectional SEM observation. The experimental results revealed reasonable evidences using nanoscale powder could sinter at lower temperature but was not easily full-filled the feedstock into narrow cavity molds. It can be concluded that the manufacturing method named NIL/ μ -SPiMIM proposed in this study has great potential to produce precisely 3 dimensional complex metallic parts with the micro-structures.

Parametric Optimization of Metal Injection Molding (MIM) Process Using ANOVA and ANNs

Md. Hamiuddin and Praveen Pachauri

The goal of this work is to identify the most significant processing parameters in Metal Injection Molding (MIM) to produce a green part for debinding. The parameters that influence green part qualities have been optimized using Taguchi L27 orthogonal array. Molding variables involved in the optimization are the injection pressure, injection temperature, mold temperature, holding pressure, injection rate, powder loading, holding time, and cooling time. The ANOVA and artificial neural networks (ANNs) are employed to determine contribution of the variables to the green qualities. Results show that the mold temperature and holding time are highly significant factors to the green qualities, while the holding pressure and cooling time do not show any significant effect.