Returning to the ‘roots’ of technology

Joseph Capus reports from MIM2012 in San Diego, which was predominantly devoted to ferrous materials and their processing, with a smaller focus on the hardmetals and non-metallic injection moulding sectors.

The MIM2012 Conference on Injection Moulding of Metals, Ceramics and Carbides, sponsored by the Metal Injection Moulding Association, a trade association of MPIF, was held 19-21 March at the Sheraton San Diego Hotel and Marina, San Diego, California. As usual, the conference was preceded by a day-long tutorial on powder injection moulding, given by Professor Randall M. German, dean of engineering research, San Diego State University (Figure 1). In addition to a keynote luncheon speaker from the firearms manufacturing industry, the conference featured a showing of the newly released video on metal injection moulding entitled, “PM and MIM: Touching your Life”.

Attendance at the conference and tutorial was close to 140, similar to the previous year. Delegates were welcomed by James P. Adams, director, technical services at MPIF, who introduced the conference co-chairmen, Bruce Dionne of Megamet Solid Metals, Inc (Figure 2) and Toby Tingskog of Sandvik Osprey Ltd.

Prof German also kicked off the conference sessions with a fast-paced historical review of MIM, tracing developments from early patents, first demonstrations in the 1940s, first commercial production in the 1970s, through to first financial success in the 1990s. He briefly noted the contributions of many of the leading characters in the development of the technology and pointed out the often overlooked role played by the introduction of the micro-processor in the achievement of successful manufacture. The resulting improvement in process control during debinding and sintering enabled sales, which had been stalled below the $US10 million level until the mid-1980s, to take off in the 1990s – reaching a global level of close to $US1 billion by 2010. As indicated in Figure 3, MIM has gradually become the dominant sector of the total powder injection moulding market.

The rest of the morning sessions were mostly devoted to various aspects of alloy and stainless steels and resulting feedstock material properties. Tim McCabe of Kinetics Climax Inc, a division of Freeport-McMoRan Copper and Gold, reviewed some of the problems encountered when oversized particles turned up in MIM feedstock materials. Because the feedstock is required to flow through narrow gates and into fine surface detail in the mould, powder particles must be finer than these features. He illustrated this with examples of oversized particles, agglomerated flakes, and non-metallic (slag) particles in ranges up to 1000 microns that have been found in nominally fine powders. Although only very small percentages of parts may be affected, the oversize material can increase wear on the mixing and moulding equipment, in addition to creating filling and packing difficulties, as well as cosmetic imperfections. McCabe said that one of the factors contributing to this situation was that the sample sizes used for powder testing were so small when compared with the production quantities.
that a few large particles in a batch could easily be missed. He recommended that users work closely with their powder suppliers to avoid surprises and find solutions to specific problems.

Philip McCalla of Megamet Solid Metals Inc reported on a study of mechanical properties of MIM 8750, a Mn-Ni-Cr-Mo low-alloy steel that was said to be fairly new to MIM. Megamet had been using this material commercially for about four years. McCalla gave results for standard test bars in a number of conditions: as-sintered, after HIPing at either 2050°F (1121°C) or 2125°F (1163°C), with and without subsequent heat treating. As shown in Table 1, this proved to be a really good material for MIM part production with properties similar to the more popular 4340-type low-alloy steel composition. McCalla indicated that the alloy had been used successfully on a couple of problematic MIM parts, and a more detailed account was promised for the MPIF’s 2012 PowderMet conference in Nashville, Tennessee, USA.

MIM2012 conference co-chairman Toby Tingskog (Figure 4), with colleagues from Sandvik Osprey Ltd, UK, and TCK, S.A., Dominican Republic, presented properties results for MIM AISI 4605 low-alloy steel prepared via a master-alloy route. In this approach, the nickel and molybdenum alloy ingredients, in the form of a gas-atomised master alloy in which the alloys are at five times the target concentrations, are blended with carbonyl iron powder. Several advantages are claimed for this method: fewer blend constituents, hence simpler operation and less risk of segregation; low-carbon master alloys can enable the use of cheaper high-carbon grades of carbonyl iron powder; improved chemical consistency with control of carbon and lower impurities; activated sintering at lower temperatures and higher finished density and mechanical properties. Mechanical property test results for the master-alloy materials compared favourably with the conventional route using blended elemental powders. Strength and hardness results varied with the sintering temperature and exceeded the book values (Figure 5).

For an entirely different alloy system, Rajendra Kelkar of GE Aviation described some of the merits of using MIM to manufacture high-temperature gas turbine components in Alloy 188, a cobalt-based superalloy. Because of their high-temperature oxidation resistance, there are major applications for cobalt-based superalloys in gas turbine combustors and exhaust components. The MIM alloy has advantages versus precision investment casting due to finer grain size and the avoidance of casting difficulties caused by the presence of lanthanum in the composition. Because of confidentiality issues, there was only a minimum of information available on this material.

Turning to feedstock based on high-strength stainless steel materials, FloMet LLC’s Ashley Nichols discussed the search for an improved binder system required to make a very challenging new part that was much heavier than usually produced. The part was in the form of a long (~5 in, 125 mm), flat,
thin (0.03 inch, 0.08 mm) blade, joined to a much thicker section (Figure 6). The stainless alloy was heat-treated 17-4 PH, H900. Problems included flow of the feedstock during moulding, together with distortion at each step of the process. After development trials with 10 different feedstocks, during which thousands of trial parts were made, Nichols said that the part was now in production with an annual volume of over 10,000 a year.

Greg Goto, Parmatech Corp, recounted the process of qualifying a new supply of hardenable martensitic stainless steel 420 MIM powder – in this case, replacing a gas-atomised powder with a water-atomised product of finer particle size. The gas-atomised powder was replaced in increments of 25%. The feedstock viscosity was increased with increases in the replacement powder, but similar moulding characteristics were achieved by modifying the binder system, without changing the powder loading. The replacement feedstock provided better sinterability (finer particle size: D<sub>90</sub> of 12.8 microns versus 27.4 microns) and met MPIF Standard 35 specifications with or without HIPing. However, a density of 99.5+ % was achieved with post-MIM HIP for both powders. In conclusion, Goto was not advocating either one of the stainless steel powders but emphasized that the effects of powder properties on MIM processing had to be considered when changing or re-qualifying materials suppliers.

**Firearms and MIM**

An interesting perspective from the viewpoint of a practitioner of a competing technology was provided by the keynote luncheon speaker, Joseph J. Zajk, chief engineer – pistols, at Sturm, Ruger & Co, Inc (Figure 7). Also known as Ruger® Firearms, Sturm, Ruger & Co was founded in 1949 and quickly grew to become one of the leading firearms manufacturers in the USA, producing a complete range of rifles, shotguns, pistols, and revolvers, notably for the commercial sporting market.

Zajk explained that Ruger’s reputation for rugged, reliable firearms has been largely due to its expertise in precision investment casting. More recently, MIM has emerged as a means of complementing Ruger’s hallmark method of manufacture for intricate, complex firearms components in a cost-effective manner. He briefly reviewed the history of Sturm, Ruger & Co and its involvement in investment casting (IC) for more than half a century. In addition to ferrous castings, Ruger has also operated Al alloy and Titanium alloy IC foundries in separate locations. Since 2007, IC operations have been consolidated in Newport, New Hampshire. The company currently has a large repertoire of investment castings.

In the late 1990s, Ruger turned to MIM to convert some of the component manufacture from investment casting. Zajk noted that the maturity of MIM as a manufacturing process coincided with the changing firearms market – smaller, lighter, more compact (especially handguns). As a result, some firearms component types that Ruger traditionally cast have become smaller, thinner, or both. This made IC more of a challenge. Zajk illustrated these aspects with
a series of case study examples, including a bolt action extractor for a rifle that was converted to MIM in 1997/98, and a revolver ejector, also in heat-treated stainless steel, for the lightweight compact revolver (LCR) introduced in 2009 (Figure 8). Due to the small size and weight of the LCR, many components traditionally manufactured by IC were no longer a good fit for that process. In a third case study, the crane (or yoke) for the LCR proved to be problematic for MIM production on account of debinding and straightness issues, and the need for cored holes. As a result, there was no compelling reason to use MIM.

In conclusion, Zajk noted that MIM technology complements and overlaps precision IC for firearms components. MIM offers more net-shape potential (viz-a-viz investment casting) and can produce thinner-walled shapes and deep holes, as well as smaller components. The upper bound of MIM part sizes overlaps the lower end of investment casting, but part geometry can strongly influence whether MIM or IC is the best fit. Finally, to give more flexibility to firearms designers, he appealed for more materials options, particularly in hardenable stainless materials, with more data on notched impact toughness in various conditions.

Short presentations
After lunch, speakers from several supplier companies gave a series of short presentations on recent developments in their products and manufacturing facilities. Tom Pelletiers of SCM Metal Products Inc gave an update on the recovery at the Hachinohe plant of Epson Atmix, Japan, following the devastating earthquake and tsunami of 2011. Production had been resumed later in the year, and the company had announced plans to build a new expanded facility on higher ground. The expansion of its fine water-atomised powder plant will raise capacity to 10,000 t/yr of -20 micron ferrous-based powders, versus current capacity of 3,000 tonnes.

Sandvik Osprey’s Martin Kearns also reported on a capacity expansion at the company’s plant in Neath, South Wales. A new gas atomizer due to start up in June 2012, together with other investments, is expected to double MIM powder capacity by year end. Sandvik Osprey has specialized in customized gas-atomized powder production over many years and has accumulated a database of about 2000 alloys. Founded in 1974 by three researchers from Swansea University, who patented the ‘Osprey (spray-forming) process’ and owned outright by Sandvik since 1985, Sandvik Osprey continues to invest in new technology and equipment, and enjoyed a record year in 2011.

Several representatives of furnace companies and other equipment suppliers gave updates on their capabilities for debinding and sintering of injection moulded parts. This theme was carried through to the evening at a table-top exhibition and networking reception (Figures 9 and 10).

Speakers at the Wednesday morning session delved into some of the advances in MIM part production technology. From the academic front, Thierry Barrière, FEMTO-ST Institute, Besançon, France, described experimental and modelling/simulation work on the preparation and rheological properties of a feedstock based on 316L.
stainless steel powder. The binder used was polymer/wax/stearic acid, and the experiments were aided by the use of a twin-screw mixer fitted with a transparent front wall, enabling progress of the temperature changes to be observed by an infra-red camera. Results showed a close agreement between numerical simulation and experimental observations with a maximum deviation of just over 2%.

In a separate talk, Barrière presented the results of an exploratory programme aimed at forming microstructured glass parts from boro-silicate (Pyrex) glass powder by injection moulding. Critical parameters were determined for feedstock preparation, debinding and sintering.

From Karlsruhe Institute of Technology, Germany, Elvira Honza took the discussion into the world of micro-injection moulding in two papers. In the first presentation, she gave results of a comparative study of micro-injection moulding aimed at improving the reproduction of micro surface features as well as the part density. This was accomplished by designing the mould to allow the injected zirconia powder feedstock to be compressed using a modified commercial injection moulding machine. In the second paper, Honza discussed another variant of micro-injection moulding: the fabrication of two-component parts by the combination of nano-scale and micro-scale powders. Nano-scale powders are not very suitable for injection moulding because of viscosity problems in the feedstock. Honza described experiments combining tape-casting of nanoscale powder with injection moulding of micro-scale powder. The influence of several processing parameters were evaluated for the case of zirconia powders. Examination of microstructures of the resulting two-component parts showed the achievement of defect-free bonding between the former tape and feedstock.

Animesh Bose of Materials Processing, Inc reviewed the status of injection-moulded hardmetals. Although mainly used for cutting tools and dies, hardmetals, or cemented carbides, are usually processed by conventional PM: pressing or cold isostatic pressing and sintering. Bose pointed out that PIM processing had so far gained little popularity in hardmetal production, mainly for economic reasons. However, he went on to explain a special niche that had developed for certain complex-shaped wear parts. These parts can be fairly large in size (from <1 g to >1 kg) compared with typical MIM components. The number of parts may also be quite low: 100-1000 per year. Injection moulding of hardmetals poses a number of technical challenges, such as much finer particle size versus conventional MIM powders, requiring special binders and higher moulding pressure, etc. Compared with the alternative of pre-forming and machining, MIM eliminates many shaping operations, reduces wasted material, and can be used with soft tooling such as aluminium or bronze, among other advantages. Bose concluded by showing a few examples including a 13 cm long twist blade and a 2 cm diameter wear-resistant cone.

Mats Gärdin, Avure Technologies, Sweden, expounded on the benefits of hot isostatic pressing (HIP) in relation to MIM parts. Not only does HIP improve properties such as strength, ductility and fatigue life, but the new generation of small HIP machines can reduce costs significantly. The latter is through the possibility of running three cycles in one eight-hour shift. The faster cooling cycles also mean that many MIM parts can be heat-treated in the same standard HIP equipment. This is partly due to the higher heat-transfer of the pressurized gas. The temperature cycle can also be programmed, making the HIP machine “the ultimate heat-treating equipment”.

Finally, Paul Hauck of Kinetics Climax Inc reviewed what the customers were now expecting from MIM producers in terms of product development and product launch, in addition to the production of highly sophisticated part shapes with substantial cost savings. The same cost savings have in the past enabled MIM producers to benefit from customer tolerance of “unplanned product variability”. In so doing, he gave a rousing challenge to any complacency in the industry.

Hauck pointed out that the current automotive and medical (implants) markets now expect much shorter product development cycles as well as more sophisticated planning and control. From his own company’s experience, Hauck then gave an example of the product development, process control, and quality management systems now required of the MIM parts producing industry.