Metal and Ceramic Injection Molding—Technical Status and Future Challenges

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ABSTRACT

Powder injection molding (PIM) in various forms has been practiced for 60 years, but significant growth occurred only in the past 10 years. Due to wider acceptance of metallic materials, ceramic powder injection molding has fallen behind the metallic version, while carbide producers still consider the technology a secret. The underlying process, products, applications, materials, and growth prospects are introduced in this talk with less attention to the specific material. As the powder injection molding community matures, the technology has moved from a pocket, localized customer base to global bidding, global customers, and a need for standardized processes. However, there are many remaining barriers. Some comments will be offered on the research trends that might significantly impact the technology, including introductions to microminiature molding, titanium products, continuous processing, very large scale production, and two-material molding. Several challenges exist and efforts to implement PIM for the production of large shapes have been frustrated by powder cost, but not technology. On the other hand, significant developments are occurring in computer models as evident from conferences such as PIM 2005. Like plastic molding, powder injection molding is currently highly fragmented and lacking in a central technical community.

GLOBAL SOURCING

Global sourcing leads to large and often very profitable opportunities for the PIM industry. However, global sourcing also begins with a partition of the PIM companies, where about half of the companies operate as regional actors that are not competitive on a global basis. The next level is comprised of the national actors that are restricted to national level competition. As with so much in life, the 80-20 rule applies to PIM. A little more than 20% of the firms are global actors (it is actually near 30%, but some are captive and not bidding against the custom molders) and they account for 80 % of the business. Only the global actors can handle the large orders.

Small companies can survive on local orders, where there is only small shop competition. Larger firms only want the very large orders, so they must transform into being global actors with an international presence. One of the surprises as a firm moves into global arena is how much better the competitors become in pricing, manufacturing systems, product knowledge, tool and process design, and overall perspective.

When a PIM part is sourced on a global basis, the customer has strong expectations for the type of firm and the infrastructure in that firm. These characteristics typical to global actors in PIM include a developed manufacturing system with integrated quality systems, industry experts in leadership positions, competitive pricing, a focus on customer service, stability, infrastructure, and an ability to deliver the final component including outsourced secondary steps. These are all parts of the audit performed with a purchasing team inspects a vendor.

GLOBAL MARKETING

A large problem in PIM is that most of the firms fail to send out a global marketing message. Most of the messages are trivial and regional, even for firms that are trying to be global actors. Most of the firms do not stand back and look at the message they are projecting. Take a look at some of the company brochures, advertisements, and sales presentations, and holes become very evident. If we score the companies versus the global, multinational buyer expectations, then most PIM firms have only a 50 % grade – failing. Global purchasing teams look for vendors with 85 % or better grade.

Our analysis of many different PIM firms shows that most are sending out a niche message (local actor or special production) and fail to attract the attention to qualify for the larger orders. PIM has yet to graduate up to a position to take on the large volume applications – say those $300 million per year orders.

Interestingly, what is being conveyed by PIM is introspective detail. For example consider some of the things PIM says to its prospective customer – really objectionable messages such as "here are our rules on process details, materials, and parts we make." Most important, instead of attracting potential customers these rules, limits, and proprietary message scare off the larger orders. Worse, are the several company brochures that focus on the news of the owner and his history, and even hobbies or charitable activities. We do not see GM selling cars with that message, so why should PIM be so introspective?

The photos in Fig. 1 are of a few images taken from PIM company brochures and sales packages showing projections of low sophistication – all send the wrong message from "it is ductile" (we need to know quantitatively how ductile), to my "office view" (what will this view do to help the customer), to "lab scale furnace" (not going to be able to sinter much volume here), to an "ancient image analysis system" (where is the benefit to the customer", and finally "we hand clean parts" (no sophistication here). All are the wrong message.

Figure 1: Wrong images from PIM.

The photos in Fig. 2 are much better images for PIM. They show the capability for large volume manufacturing, automation, awards, and significant capital investment.

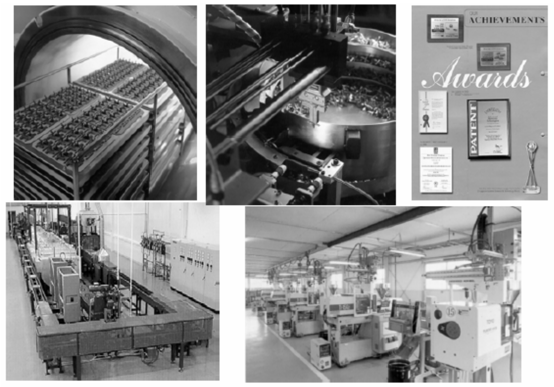

Figure 2: Right images from PIM

GLOBAL CUSTOMERS

PIM has some great successes, and we need to leverage into larger orders via leveraging from name recognition – just for example look at the implication from Fig. 3.

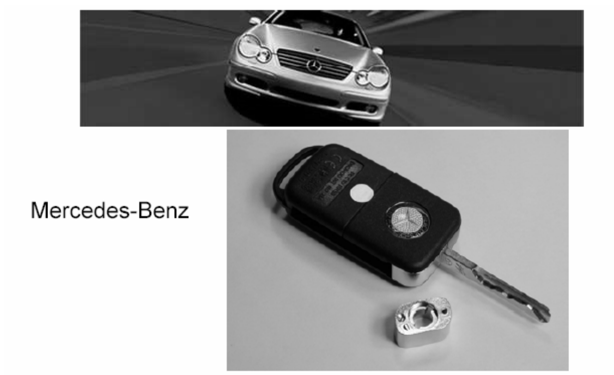

Figure 3: Name recognition as a needed message from PIM.

The Motorola experience (Fig. 4) helped PIM reach very important quality, quantity, and pricing goals. More than anything else, we need to sell that message that PIM is not experimental.

Figure 4: We need images that show PIM is not experimental.

As another example, we find that in many cases the industry and user community is not even told PIM is the production route. Why should the customer care if the product works properly. Fig. 5 is one example using a cemented carbide cutting tip, used in drilling. This part has a value of $14,000 per kg, which exceeds the cost of gold, yet nowhere is there mention of PIM as the production process. Essentially the product is solving a problem and the production route is not the selling proposition. Unfortunately, most of the firms seem to want to sell the technology and not the solutions.

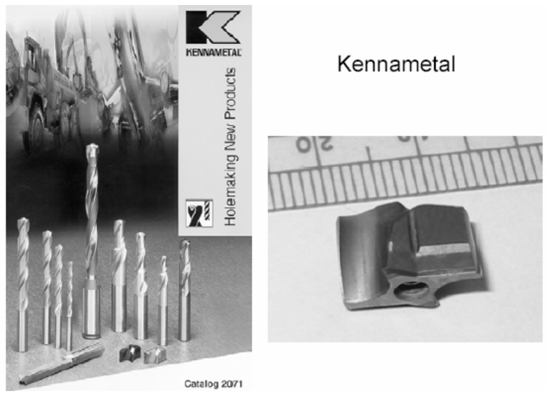

Figure 5: An example of a high-value PIM product.

As another example, Fig. 6 shows an award winning design by PIM that demonstrates how the technology provides solutions for very demanding applications. Consumer products are another area where PIM has an established record of large-scale, consistent production. For example, the watch case shown in Fig. 7 is one compelling demonstration on how PIM is accepted and safe for large, high volume applications. Indeed, there are so many of these situations in practice, that often the PIM firms are surprised by the diverse listing of successes.

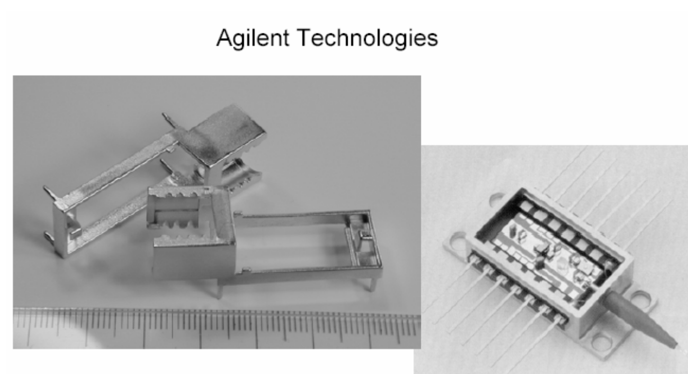

Figure 6: Another demonstration of PIM in solving problems, as evident by this award winning design

Figure 7: An example of a high-volume consumer product application that helps project safety to the global customers who want to use PIM.

Likewise, the mailbox lock in Fig. 8 represents a production volume of 32 million units per year, and is one of the many PIM successes that PIM should be using to attract more of the large-volume users who do not want an experimental technology.

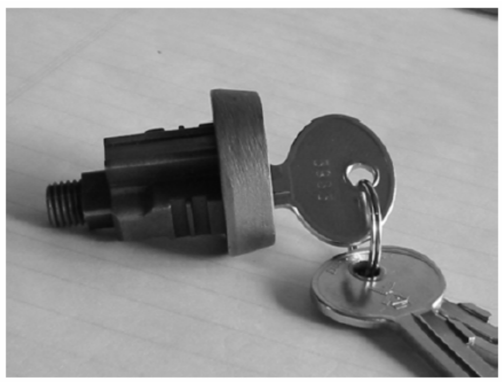

Figure 8: A mailbox lock that might reach millions of units per year by PIM.

The shape complexity attainable via PIM is a clear advantage, especially for smaller objects. Fig. 9 illustrates some complicated shapes fabricated by PIM for cellular telephones.

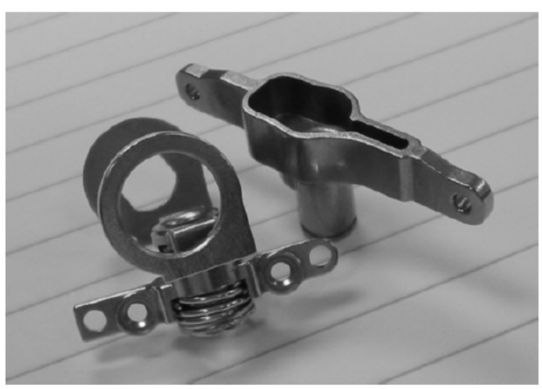

Figure 9: Complexity in PIM as evident in these cellular telephone parts.

As another example, Fig. 10 is a picture of a high performance end mill fabricated out of cemented carbide compositions using PIM. This is used in very demanding application.

SECO Tool

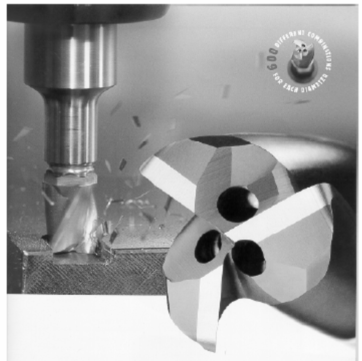

Figure 10: A picture of an end mill with integrated cooling holes fabricated using PIM.

Finally, again an issue that most of the PIM industry ignores, showing how the technology has penetrated into all aspects of life. Fig. 11 is such a demonstration and most of those in the field were not familiar with this success. It is hard to sell the large customers if we do not even know of our successes.

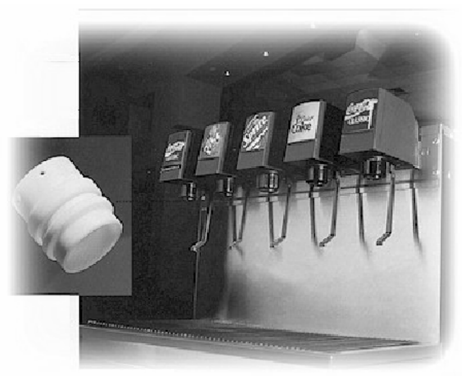

Figure 11: A simple message showing how PIM can be used to fabricate commonplace items

GLOBAL DESIGNS, DESIGN GUIDES

We need to sell benefits, not features. Tell the designer the benefits – such as the rate of production is from 1 per second – not the number of cavities. Tell them that shape complexity comes at a low cost. Large production quantities are possible, but stop telling our restrictions. I have complained that some of the companies brag they can produce xxx parts or xxx kg per month, but there are projects on the horizon that require 2x, 3x, and even 10x those values. Such constrictive messages scare off very good opportunities. Other favorable concepts we should be promoting in our message relates to sophistication – PIM is cost effective, delivers handbook properties, and is accepted by major corporations. Name recognition is valuable with most designers, since they tend to be less experimental than generally recognized, especially when dealing with large orders which PIM so much craves.

Unfortunately, the common tables showing allowed size and shape data in design guides, are not useful. Better yet, show parts and talk about the PIM process excels in material utilization as a difference from machining (Fig. 12). PIM excels with low effective density and "complexity at little extra cost."

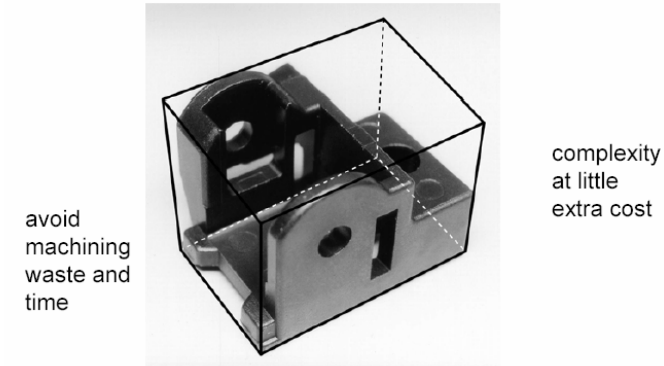

Figure 12: Effective density is an easy means to providing a designer with a working concept on viable PIM candidates.

The statistical profile on current PIM production, in terms of percent effective density, is shown in Fig. 13. This plot demonstrates that most commercial successes would result in over 70 % material loss in machining.

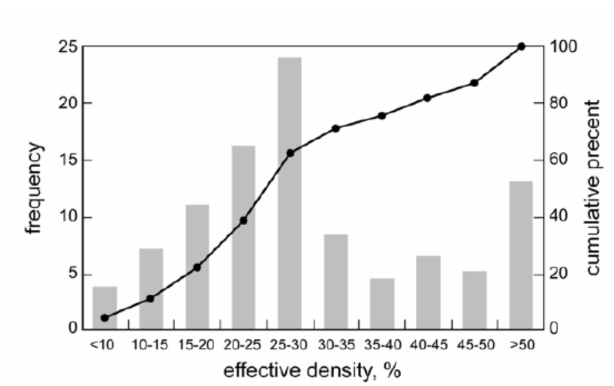

Figure 13: Histogram and cumulative distributions showing the effective density (component mass divided by total volume required if machined from wrought metal) for PIM.

The message is clear. PIM is useful when machining would be difficult. However, because of raw material cost, we must discourage applications that are very large, so distribution plots of what are the typical size and shape ranges are very effective. Fig. 14 shows the results of recent audits of PIM. These two distribution plots show the designer the mass range and maximum size range compatible with PIM. Other plots have been generated to capture the distributions in wall thickness, number of features, and projected area, slenderness, and other important features.

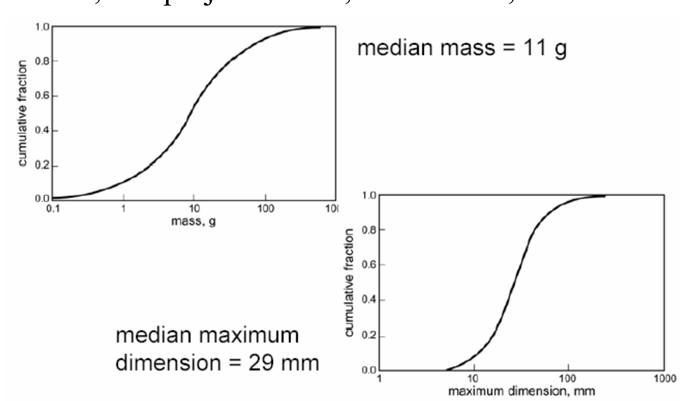

Figure 14: Statistical samplings showing the mass and maximum size distributions found in commercial PIM.

Four more design distributions are given in Fig. 15 to show the wall thickness (maximum and minimum in a part), outside volume, projected area on parting line, and number of features in the design. All are quick ways to convey design windows without long inventories of linear rules, which is the current approach.

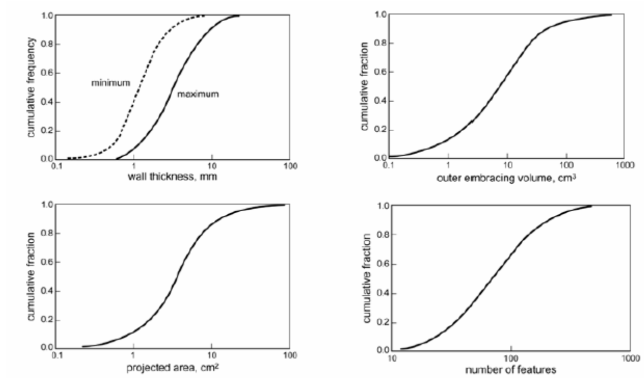

Figure 15: Statistical descriptions of the design distributions found in production PIM components.

Further, rather than taking exception to the properties, show the designer that PIM delivers handbook properties. This for example is plotted in Fig. 16 where the yield strength of PIM metallic compositions is directly compared to the handbook values, showing a 95% correlation. Indeed, many of the PIM values are higher than the handbook values, suggesting the PIM exceeds the designer expectations

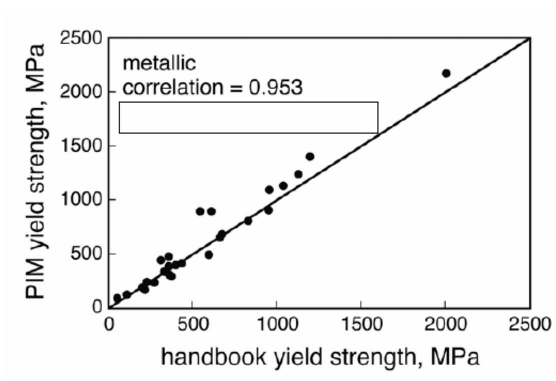

Figure 16: Comparison of yield strength values in PIM alloys with handbook properties

We can help the design with simple plots such as that given in Fig. 17.

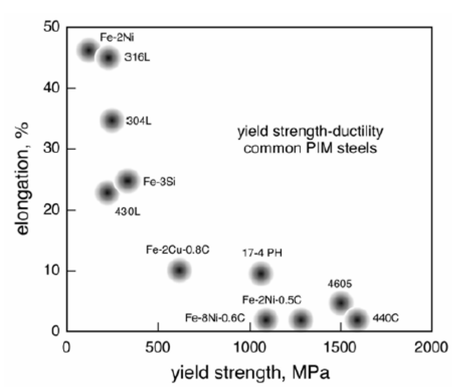

Figure 17: Alloy selection for PIM materials in terms of a simple ductility-strength scatter plot

Figure 18 is another scatter diagram showing relative corrosion resistance and yield strength, to guide the designer toward a successful experience with PIM.

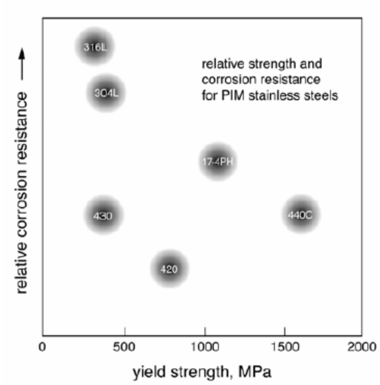

Figure 18: Alloy selection for PIM based on a scatter diagram of strength and corrosion resistance. Simple diagrams of this sort are very effective with the design community.

NEED FOR A CONSISTENT MESSAGE

A problem is the need for a consistent message. The photo in Fig. 19 is a simple message showing scissors with a constant wall thickness, a favorable PIM attribute.

constant
wall thickness
slender part

Figure 19: The ceramic blades from these scissors are a good illustration of how PIM excels with a constant wall thickness.

Our goal in these efforts are to make the design community feel comfortable with PIM and to not appear experimental. Experimental technologies have only 5 to 10 % customer acceptance, so we need to grow beyond that to become mainstream. In short the PIM community needs to stop sending a niche technology message and to project an image of a sophisticated and accepted manufacturing process. The bottom line message needs to be that PIM is a safe choice for the global sourcing opportunities.

COMPUTER MODELS

Significant progress has taken place in the last few years in computer modeling most aspects of the PIM process, from tool design, heat transfer, mold filling, powder-binder separation, debinding, and sintering. However, most of this is in the hands of the research and development community, but not reaching the production operations. This is probably due to three factors.

First is the lack of adequately trained engineers at most of the PIM operations. The engineering ranks are thin and the age of that talent shows in terms of familiarity with contemporary engineering analysis tools. Second, are the costs. These computer packages require time, effort, and considerable expense to implement. Many of the PIM operations do not have the top-down motivation to invest to implement these productivity improvement tools. It is similar to the story of the lumberjack who falls further and further behind schedule, claiming then he does not have enough time to stop and sharpen the saw. Third, there are several offerings and most engineers can not pick between these to identify which will be the most accommodating to their practice. Likewise, each computer simulation requires a new form of data for the rheology, pressure-temperature-volume relation, and other basic properties. Fig. 20 is just one example of the solutions being generated using personal computer systems, in this case showing the distribution in fill times over the image of a printer yoke.

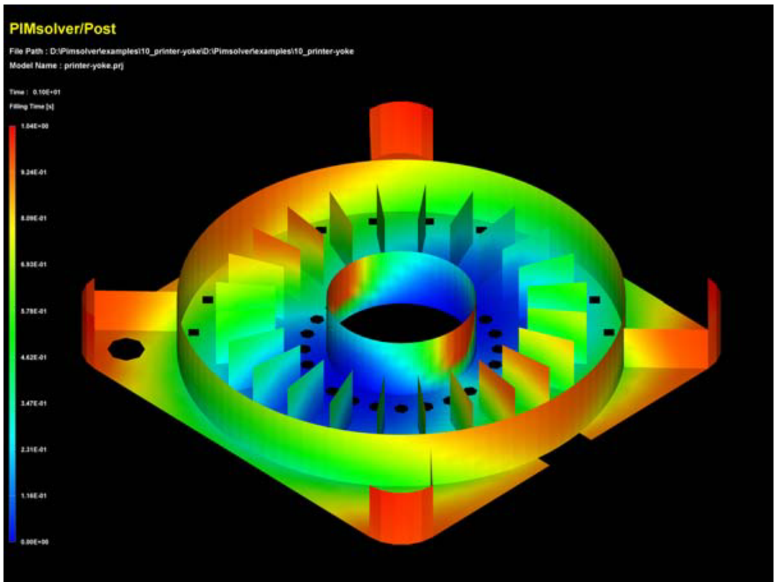

Fig. 20. A computer simulated plot of the fill time for PIM molding of a printer yoke.

Most of the simulations have been fairly successful in the mold filling stage, especially with respect to gate size and gate placement, vent placement, weld line formation, and defect prevention. However, the true test comes in predicting the final component size, shape, and quality from first calculations. In that regard the simulations are making great progress on various demonstration components.

KEY POINTS

So back to the title and key points for this paper and presentation, as PIM finally enters the global market, we see that sophistication and cost competition increase. To be accepted by the large multi-national users, the PIM community needs to address how to project this technology as being established and accepted. Clearly, the PIM industry needs to move from selling features (we use batch sintering) to selling benefits (complexity at little extra cost). This means a fundamental transition from niche messages to more sophisticated messages showing how PIM can be sold as a successful, accepted, and effective technology. Recognition will grow by leveraging off our prior successes and embracing contemporary tools, such as the new mold filling simulations and sintering simulations. There is massive opportunity.

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