An Analysis of the Powder Injection Molding Industry Global Market

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ABSTRACT

An analysis of the powder injection molding (PIM) worldwide industry is underway. Data are being collected and analyzed and will cover technologies, markets, trends, applications, sales, properties, and profits. Data collection methods include industry surveys, conversations, database searches, and verification surveys and reports. Profiles on powder and feedstock suppliers, equipment manufacturers, parts makers and major users have been included. Relevant patents have been collected and abstracts will be given as well as literature that has been published in the field. The field is defined as both ceramic and metal systems and even includes some new combinatorial material systems only possible by a powder approach (including cemented carbides). The analysis has been broken down geographically to North America, Europe and Eastern Asia with data presented worldwide. PIM can be defined as an advanced manufacturing technology and is aligned with the evolution of advanced materials, formed to net-shapes and used in a wide variety of industrial and consumer product applications. The industry as a whole is strong and continues to grow at a surprisingly strong 40% annual rate. Continually, companies are investigating the technology and implementing either their own manufacturing capability or making the decision to buy from or acquire existing manufacturers.

TECHNOLOGY

PIM is the process of manufacturing metal and ceramic parts from small powders (normally around 20 micrometers or less) using injection molding technologies, typically used by the plastic industry to manufacture high volume components. Metal and ceramic components can be made by preparing a feedstock of powders and polymers that can be processed on a standard low or high-pressure molding machine. The components are removed from the die and the binder system is extracted chemically, thermally or by a combination method. The components are then consolidated by heating to a temperature just below the melting temperature until near full density is reached. This sintering process is well known to the ceramics and powder metal industries. Final components have the mechanical properties of other full density metal and ceramic components formed by conventional manufacturing techniques like machining, stamping and forging.

MARKETS

Worldwide there are more than 525 companies with direct employment in PIM parts production. Additionally many powder suppliers, equipment vendors, research institutes, consultants and professional organizations are involved in promoting the technology totaling more than 6000 people. These activities amount to another 1000 firms. The commercial value of PIM production for the year 2000 is estimated to exceed $800 million in sales and is growing rapidly. The identified market for components exceeds $2 billion by 2009 in present day dollars.

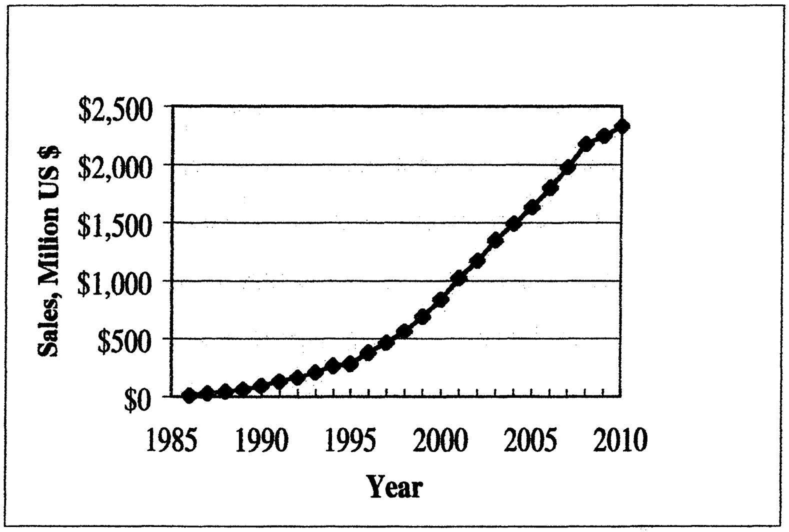

Figure 1. PIM Sales History and Forecast

Roughly half of all production is by companies that use the components for internal products (captive). Custom manufacturers make up the other half of the industry and are made up of a large number of smaller companies that manufacture custom components on a bidding basis. Several of these firms have been highly successful and have expanded in the last couple of years to meet customer demands. Additionally, plastics parts manufacturers are beginning to see the value of expanding their product offerings and have begun or are investigating PIM. Table 1 lists several parts applications and whether they are most likely produced by companies making for internal consumption or by a custom parts fabricator.

MATERIALS

A wide variety of commercial ceramic, metal and carbide materials are available via PIM with stainless steel, alumina, silica, iron, and various lower carbon steel grades dominating the market. The value of metallic and ceramic parts production by PIM is relatively equal, although there are differences in how the markets operate. In ceramic production, many of the components are larger, and sell at a lower price. Also, for commercial production, ceramic companies tend to make parts by a variety of manufacturing technologies e.g., they use uniaxial compaction, CIP, PIM, and tape casting. One of the largest segments of the ceramics PIM market is manufacture of casting cores for high performance turbine applications. They manufacture a silica or alumina airfoil shape that is destroyed in the manufacturing process. Essentially a complex shape is

Market	Internal Usage	Custom Parts Fabricator	Market	Internal Usage	Custom Parts Fabricator
orthodontic brackets	X	X	oxygen sensors	X	
firearm components	X	X	spray nozzles	X	X
cameras	X	X	wear components	X	X
business machine parts	X	X	computer disk drives		X
casting refractories	X		locks		X
cutting tools	X		turbochargers	X	X
microelectronics packaging	X		connectors		X
wirebonding	X		personal care		X
wristwatch cases and parts	X		fiber optical connectors		X
jewelry	X		sporting goods		X
investment casting cores	X		radiation shields		X
thread guides	X		automotive parts		X
automotive airbag components	X	X	plumbing fixtures		X
biomedical implants	X		small engine parts/valves		X
surgical tools	X	X	oil well production tools		X
jewelry	X	X	wood cutting tools	X	X
oil well production tools		X	hand tools		X
wood cutting tools	X	X	fiber optical connectors		X
hot runner systems	X		fuel injectors		X
hardware	X	X	sewing machines		X
cutlery	X	X	casting refractories	X	X

Table 1 PIM Part Applications

injection molded out of the ceramic and then a high performance metal is cast around the ceramic insert. The insert is then chemically leached out of the preform, creating a complex shaped hollow turbine blade. This technology utilizes low-pressure molding and a great deal of handwork to finish the part. Other ceramic producers that are highly profitable include the shaping of nonoxide ceramics – silicon nitride, silicon carbide, and aluminum nitride type materials.

Based on sales, alumina and silica make up roughly a quarter of the industry, stainless steel and iron-based materials make up about half of the industry with the other ceramics and metals making up the remaining industry. On a sales basis, stainless steel dominates the PIM industry including powder purchases and value of finished components. In most cases carbon is fully extracted, so carbon control is relatively easy, making stainless steels the largest growing material system and may have the largest potential for moving PIM into new applications.

Cemented carbides, a small but growing segment of the industry find applications in wear components and tooling. Because of difficulties in coupling to designs for these high wear applications the technology is moving slowly in this field, but recent advances coupling to designs for these feedstocks and processing are leading to increased growth.

Increasingly companies are turning to feedstock suppliers as opposed to compounding the material themselves. There are currently 20 companies that indicate that they have commercially available metal and or ceramic feedstocks. We see fewer powder suppliers and some of these may look to manufacture feedstocks as value-added products. As more and more companies turn to preformulated feedstocks, the technology will continue to grow because of greater part-to-part uniformity. We expect that there will be consolidations in the PIM industry in the next several years. Already, offers have been made for several of the smaller firms. A primary example is the recent acquisition of Thermat Inc. by a large medical parts manufacturer, Medsource Technologies, Inc. and the acquisition of ANVAL by Carpenter Technologies.

METRICS TO SUCCESS

Many companies continue to investigate the technology, including a large number of custom and captive plastic manufacturers, companies for in-house production of components, casting companies because of environmental concerns, and companies that manufacture machined components because of the economics. Because they are making an investment today, these companies can often enter the market fairly quickly. The know-how and metrics for success exist and can be garnered by talking with people in the industry or even buying the talent that is necessary i.e. with long-term manufacturing experience. Companies, consultants, and research organizations will provide the technical knowledge and the parameters necessary to reach profitable production in a short time. With all of the knowledge available, new operations do not need to continue to rediscover the technology. However, because this information is out there, does not mean it will be used. Many of the concerns in the industry have solutions, but they are not being addressed by all manufacturers, in some cases leading to a tarnished image for the technology. Concerns include variability between vendors because of differences in feedstock or machine capabilities, quality issues, lack of use and understanding of process fundamentals, limited intellectual knowledge base and the inability for small companies to market effectively.

DESIGN CONSIDERATIONS

Final properties of PIM materials are similar, and now even superior, to other forming processes. It is even possible to produce properties of steels rivaling those of forgings by using advanced processing schemes and improved sintering cycles. Strengths up to 3 GPa (435ksi) and 3 % elongation are possible. Other property requirements (thermal, magnetic, electrical, optical) generally are competitive with standard forming technologies. Complex shapes with high performance requirements and high production volumes are necessary to compensate for the high start-up tooling investment. History shows cost reductions of 30% or substantial performance enhancements are necessary to sell customers on PIM.

Generally, PIM is best suited for smaller, complex shaped components. Although larger components have been produced, they are unusual. More design data are available for metal components than for ceramic or carbides. In general, if a component requires 5 plus machine tool set-ups, MIM is a candidate for consideration. Table 2 gives typical design considerations.

Criteria	Typical	Maximum
Maximum length, mm	2 – 200	1000
Wall thickness, mm	0.01 – 10	25
Mass, g	0.02 – 150	20,000g
Part Cost, $	0.30 – 2.50	500.00
Production Quantity	200 – 150,000	20,000,000
Tolerances, mm	0.03 – 0.30	2.0
Surface Finish for metal parts, RMS	32	16 (with secondary operation)

Table 2. Design Criteria for PIM

Often, both metal and ceramic components requiring several machined parts can be manufactured in one step by PIM, saving material and ultimately cost. Tolerances are generally dependent on three factors: molding sophistication, binder composition and mixture homogeneity, and debinding approach. Size variations in a component are generally limited but success has been reported with combinations of thick and thin sections with up to 100 fold variation. The opportunities in micro miniature molding of components are enormous. While these components do not consume large quantities of powder, they promise high volumes in fields like biomedical, electronics, communications, and sensors. Currently design information is limited. Computer automated design (CAD) systems do not have modules with built in PIM design advisors. Increased designer training is required to continue to move the technology forward.

SCIENTIFIC IMPACT OF MIM BUSINESS

PIM technology and practice have moved into profitability because the necessary critical mass in scientific and practical knowledge has been achieved. Market growth directly correlates with the number of publications on MIM. Market pull has driven the production of powders and science has responded; new alloy powders in tailored particle size ranges are becoming available for PIM and the cost of common metal injection molding (MIM) alloys has decreased as volume has increased.

Mixing has moved toward more tightly controlled continuous techniques and feedstocks have become standardized. Several large chemical and technology companies, as well as several smaller specialty companies have developed preformulated systems available to any customers. Tooling and molding are now standard practice with much less "black art" know-how. Debinding and sintering are moving to high volume continuous processes. The cycles and protocols are well established. Recent efforts in mold-flow modeling and some modeling of debinding and sintering will add to these protocols. As a point of reference, the ten most significant developments in PIM are as follows:

Significant Developments in MIM

1. Increased awareness – training books, conferences, papers, workshops, and seminars.
2. Standardized feedstocks
3. Continuous sintering furnaces
4. Standard molding machines with closed loop feedback controls
5. Debinding rules for shape retention
6. Identification of optimal powder characteristics, implementation via water atomized powders
7. Combined debinding and sintering equipment
8. Customized continuous mixers
9. Composition control via atmosphere C-O-N-H interactions
10. Environmentally benign polymers and debinding cycles

Other factors include: a larger more knowledgeable workforce; largely ignored intellectual property; lower powder prices; and the driving forces to high volume, cost effective manufacturing technology.

PIM MATERIAL STANDARDS

Once again the metals and ceramics industries differ on how they operate. Ceramics applications tend not to follow material standards for PIM. Instead companies specify properties. The supplier and customer agree on properties before the component is put into production. Ceramics are often used for their insulation or high temperature properties and are less dependent on their structural properties or how the component is produced. Metal components, on the other hand, are very dependent on the density, processing, and grain size of the material and properties can vary greatly. As such, there are efforts underway in both North America through MPIF standards activities and even more actively in Europe through the Thematic Network, a part of the European Powder Metal Association with funding assistance from the European Community. Metals by PIM follow very closely their machined counterparts and can even have superior properties because of unique alloy systems and/or carefully controlled microstructures. In fact, the European Community has established research and development efforts in PIM in the following areas: process development, binder development, debinding, graded structures, standardization, rapid tooling. Sixteen projects are currently funded (Haupt).

PIM MARKETING

Powder injection molding is served by a host of organizations, none of which are focused on the specific needs of the industry. The European community is fairly well organized through the Thematic Network of EPMA and has 34 members. In Japan and the Far East, there is no organization that directly serves this community although each country has either a materials or processing cluster (for example the Japan Powder Metallurgy Association). In North America, Metal Powder Industries Federation (MPIF) has the Metal Injection Molding Association with approximately 25 company members. This represents less than 10 % of the parts manufacturers in North America and until recently none of the suppliers to this industry. The ceramics industry has even less focused representation on PIM with a few small organizations like the Ceramics Manufacturers Association that does nothing special for the companies that use PIM technologies. Reportedly, PIM operations are not compelled to join with competitors to unify the image as yet.

Powder injection molding has a lot to offer to a whole host of industries including more efficient manufacturing, improved properties, reduced costs, new materials; to put it simply a better way of doing business. To do this, the PIM industry needs to come together in a more cohesive, dedicated body. Existing organizations may not be able to do this if they are not able to differentiate the benefits over the established processes. We believe that the industry needs a new organization that is devoted to the market development and technology and is not restricted by other activities and special interest groups. Recently a group met to discuss moving forward with a marketing activity on behalf of the industry and will meet again during the summer of 2000. (James)

CONCLUSIONS

The PIM industry is a healthy, vibrant, industry on a fast-paced growth track. This manufacturing technology has much to offer a host of industries from jewelry makers to small engines and consumer products. The prospects are great and the industry should look forward to years of growth and prosperity as well as technical improvements that will open new markets.

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