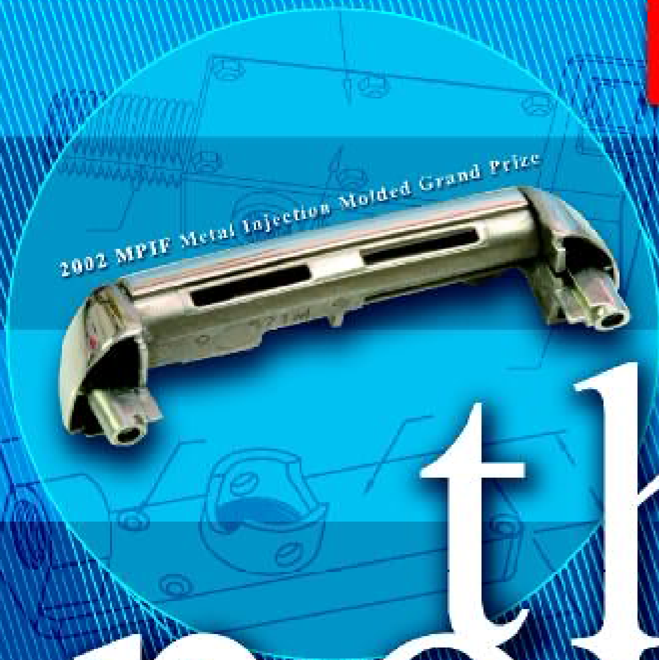
PARMATECH CORPORATION



the power of powder

PARMATECH POWDER INJECTION MOLDING DESIGN GUIDE

Where Imagination & Design Take Shape

\'in-tri-ket\

1994 MPIF Metal Injection Molded Award of Distinction

A thing is complex when it is made up of parts;
It is complicated when those parts are so many,
or so arranged, as to make it difficult to grasp them;
It is intricate when it has numerous
windings and confused involutions.
What is complex must be resolved into its parts;
What is complicated must be drawn out and developed;
What is intricate must be unraveled.

—Webster's Revised Unabridged Dictionary

\'in-tri-ket\

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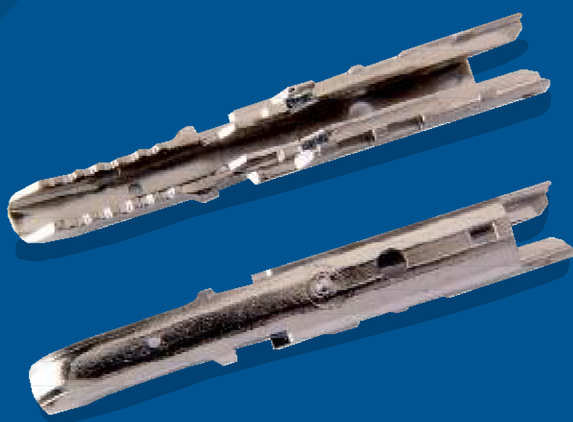

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Introduction

Parmatech routinely handles shapes and materials that are difficult or impossible for other fabricators.

This alone sets us apart from the rest.

Parmatech is a subsidiary of ATW Companies, Inc., a holding company that also includes A.T. Wall Company and Judson A. Smith Company. With nearly two centuries worth of combined experience, ATW has a vast array of capabilities including: tube fabrication, tube drawing, stamping, machining, laser fabrication, metal injection molding, and ceramic injection molding.

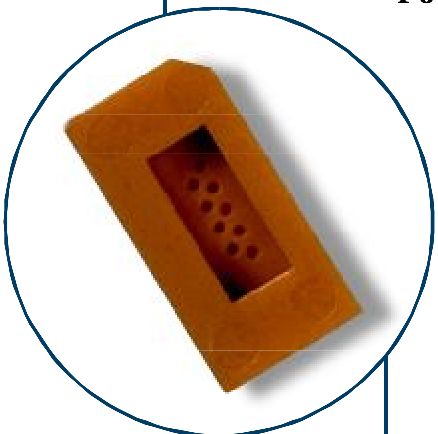
Most individuals shy away from the complex, but not Parmatech.
We thrive on intricacy, precision, and expert design. In fact, we've built our business on it.

Parmatech specializes in metal injection molding (MIM) and ceramic injection molding (CIM), collectively known as powder injection molding (PIM). For over thirty years we have been manufacturing parts for a variety of industries. Today, we are a world-class PIM organization with our manufacturing facility in Petaluma, CA. We have the unmatched ability to develop and refine materials for your application and the know-how to successfully produce your component.

1993 MPIF Metal Injection Molded Award of Distinction

The PIM Process

Powder Injection Molding



Powder injection molding was pioneered by Parmatech founder Karl Zueger. In 1973, Zueger left Fairchild Semiconductor in Silicon Valley when he saw a need for manufacturing precise, ceramic capillary tubes used for wire-bonding integrated circuits. Shortly thereafter, he patented a process for ceramic injection molding and metal injection molding.

Zueger realized that some parts, due to their size and complexity, just could not be cost effectively manufactured using traditional technologies. PIM is best suited for these small, complex components that are difficult, costly, or even impossible to fabricate using other technologies.

PARMATECH = PARticulate MAterials TECHnology

PIM has been successfully used in many industries including:

- Automotive
- Medical
- Firearms
- Telecommunications
- Consumer
- Industrial
- Computers
- Electronics

Recognition

Throughout the years we've won numerous awards for our excellence in powdered metal applications. Since 1979 Parmatech has won six Grand Prize awards, five Awards of Distinction, and two Awards of Achievement from the Metal Powder Industry Federation (MPIF). And we're still counting!

1992 MPIF Metal Injection Molded Grand Prize

The PIM Process

One Step at a Time

Parmatech works closely with customers to ensure the best production at the optimum cost. While PIM generally consists of a few main steps, we will optimize the material binder system and processing path for your application.

i Compounding

We start with a fine metal or ceramic powder (particle size approximately 1-20 microns) and mix this with a proprietary blend of materials called "binders."

The powder and binder are mixed and pelletized to form a feedstock for injection molding.

ii Molding

The feedstock is injected into a mold to form a "green" part.

Our proprietary process provides a unique solution that meets your most demanding engineering needs.

iii Debinding

The binders are removed through a combination of solvent and thermal processing.

iv Sintering

The parts are put through a high temperature sintering process that fuses the powder particles together enabling the part to achieve 96%-99% of theoretical density.

During this critical step the parts shrink approximately 20%. We utilize special techniques that result in exceptional metallurgical and dimensional controls, resulting in very repeatable and stable parts.

Depending on the annual volume of your project, the PIM process can be batch or continuous.

v Afterward . . .

After sintering, the parts are inspected against high quality standards. At this point, additional operations, such as machining, heat treating, or plating, may be undertaken to achieve tighter tolerances or enhanced properties.

What to Expect

What to Expect from Parmatech

We're passionate about what we do and we work hard to fulfill our customers' PIM needs. From beginning to end, you can depend on our support every step of the way. We like to get involved in your project as early as possible to help you incorporate the design for manufacturability (DFM) ideas presented later in this guide.

1 Design & Material Selection Assistance

Meeting with our Engineering Design & Development Team

You'll meet with our engineering design and development team who will provide guidance on:

- Materials selection & metallurgical assistance
- Tooling solutions
- Secondary operations
- Cost reduction opportunities

Discussion with a Technical Representative

You'll speak with one of our representatives about Parmatech's capabilities and what those benefits mean for you. We will listen and understand the challenges you face and then help you to identify real solutions.

2 Program Management

Engineering Review

You will be assigned a dedicated program management team to ensure your timely and successful product launch. Our team will meet with you at either your own site or Parmatech to provide an in-depth review of your complex part and determine your overall program needs.

What to Expect

Product Qualification

Our formal product development process covers all the bases. Through the use of design of experiments (DOE), capability studies, production part approval process (PPAP), and gauge repeatability and reproducibility (GR&R) studies, we ensure that the PIM process is well matched with your design requirements.

We also communicate regularly with our customers to share schedule data and project status. All of this leads to a formal customer approval and an on-time product launch.

1991 MPIF Metal Injection Molded Grand Prize

3 Manufacturing

Production

Once your part has been approved, we'll provide world-class manufacturing capabilities to meet and exceed your quality and delivery needs.

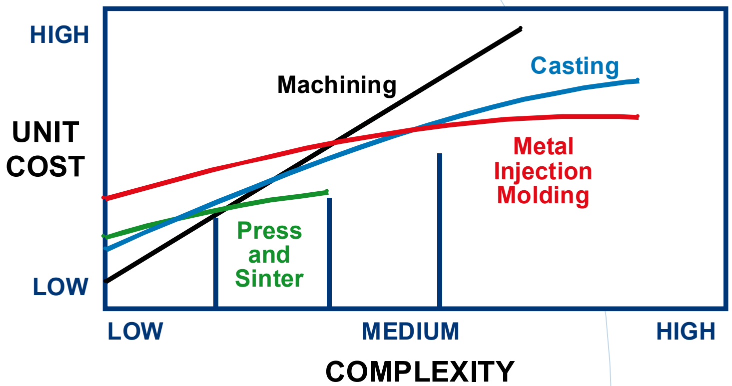
Ongoing Support & Services

Our representatives across the country are available at any time to answer your questions. Our clients tell us that our support and services are a major asset to them. Perhaps this is just one reason why they keep coming back.

PIM Part Selection Criteria

PIM Advantages

The PIM process has some inherent advantages which, when taken advantage of properly, offer tremendous cost and performance benefits. PIM excels when part usage is large, part complexity is high, and part size is small. In addition, PIM parts also feature superior density (>98%) and surface finish (32 RMS typical) properties, near net shape processing, and material selection including both metals and ceramics.



Part Selection Considerations

There are four main considerations for determining if a part is a good PIM candidate:

- Size - Annual Volume - Material - Complexity

Characteristic	Minimum	
Mass	0.01 g	0.0004 oz
Wall Thickness	0.125 mm	0.005 in
Annual Usage		25,000
Characteristic	**Maximum**	
Mass	250 g	8.82 oz
Wall Thickness	7.62 mm	0.300 in
Annual Usage		millions
Characteristic	**Optimum**	
Mass	<50 g	<1.75 oz
Wall Thickness	2.03 mm	0.080 in
Annual Usage		>100,000

At Paramatech, we work with our customers to identify critical characteristics in order to help us develop and customize a product quality plan that meets your needs.

Materials & Properties

Parmatech PIM Materials

Parmatech employs a wide range of materials catering to a variety of applications.

If your application has special requirements that aren't met with the materials on the following page, we will work closely with you to develop a material that will.

Parmatech has unmatched capabilities to develop materials that are both tailored to your needs and optimized for PIM. We utilize many qualified powder vendors that, when combined with our in-house mixing capability, constitute our material expertise.

Through the PIM process, parts typically shrink by 20%.

the power of powder™

At Parmatech, we're constantly introducing new alloys.

For our most current list, refer to our website at www.parmatech.com.

1999 MPIF Metal Injection Molded Grand Prize

Materials & Properties

Parmatech PIM Materials

Material Group	Allow/Material	Description
Low Alloy and Alloy Steels	· MIM-2200 (Fe-2%Ni) · MIM-2700 (Fe-7%Ni) · 4140	High strength and hardness when heat treated
Austenitic Stainless Steels	· 304L · MIM-316L	Excellent cryogenic properties, superior corrosion resistance, moderate strength and high ductility
Ferritic Stainless Steels	· MIM-430L	Possess good corrosion and magnetic properties
Martensitic Stainless Steels	· 420 · 440C	Designed to provide moderate corrosion resistance with excellent hardness, strength and wear
Precipitation Hardening Stainless Steels	· MIM-17-4 PH	High strength, toughness and hardness, with good corrosion resistance
Soft Magnetic Materials	· MIM-2200 (Fe-2%Ni) · MIM-Fe-50%Ni (Fe-50%Ni) · MIM-430L · MIM-Fe-3%Si (Fe-3%Si) · MIM-Fe-50%Co	Soft ferromagnetic materials
Controlled Expansion and Sealing Materials	· ASTM B388 (Invar®36) · ASTM F-30 (Low Expansion "42"® Alloy) · F-15 Alloy (Kovar®) · 50% Ni-Cu	Uniform and low thermal expansion alloys
Medical Alloys	· F-75	Non-magnetic, cobalt-chromium-molybdenum alloys exhibiting high strength, corrosion resistance and wear resistance
Heat-Resistant Alloys	· ASTM B637 (Pyromet®718)	Developed for high temperature and oxidation resistance and where relatively high stresses (tensile, thermal, vibratory, or shock) are encountered
Ceramics	· Aluminum Oxide (Alumina) · Zirconium Oxide (Zirconia) · Zirconium Oxide stabilized with MgO, CaO, or Y_2O_3 · Ruby (98% Alumina, 2% CrO) · Zirconia Toughened Alumina · Alumina Toughened Zirconia	Developed for high hardness and wear resistance
Copper	· Cu	High thermal conductivity and good electrical properties
Tungsten	· W-Cu	High thermal conductivity and density, good electrical properties

Invar®36, Low Expansion "42"® Alloy, Kovar®, and Pyromet®718 are trademarks of the Carpenter Technology Corporation

Materials & Properties

Nominal Chemical Composition (%) of Common Parmatech MIM Alloys

Alloy*	Fe	Ni	Cr	C	Si	Mo	Cu	Mn	Others
MIM-2200	Bal	1.5-2.5		0.05 max	1.0 max	0.5 max			
MIM-2700	Bal	6.5-8.5		0.05 max	1.0 max	0.5 max			
MIM-316L	Bal	10-14	16-18	0.03 max	1.0 max	2-3		2.0 max	
MIM-304 L	Bal	8-12	18-20	0.03 max	1.0 max			2.0 max	
MIM-17-4 PH	Bal	3-5	15.5-17.5	0.07 max	1.0 max		3-5	1.0 max	0.15-0.45(Nb+Ta)
420	Bal		12-14	0.20-0.35					
4140	Bal		0.9-1.2	0.32-0.42	0.15-.030			0.75-1.0	
MIM-430 L	Bal		16-18	0.02 max	1.0 max				
MIM-Fe-3%Si	Bal			0.02 max	2.5-3.5			1.0 max	
MIM-Fe-50%Ni	Bal	49-51		0.02 max	1.0 max				
MIM-Fe-50%Co	Bal			0.05 max	1.0 max				48-50 Co 2.5 Max V
F-15	Bal	29-30		0.04 max					16-17 Co

* Alloys with MIM prefix are also listed in the MPIF Standard 35 (2000 edition) Materials Standard for Metal Injection Molded Parts

Typical Electrical Properties of Parmatech MIM Alloys

Alloy	Density (g/cm^3)	Thermal Diffusivity cm^2/s	Specific Heat J/kg•K	Thermal Conductivity W/mK
Copper	>8.5	1.02	365	320

Typical Magnetic Properties of Parmatech MIM Alloys

Alloy	Density (g/cm^3)	Maximum Permeability, μ_{max}	Coercive Field H_C (Oe)	Residual Induction B_r (kG)	Induction, B(kG) @ H=		
					5 Oe	10 Oe	15 Oe
MIM-2200	7.75	3,300	1.5	7.7	12.0	14.0	15.2
MIM-2700	7.85	1,700	2.30	6.2	7.8	11.5	13.9
MIM-Fe-50%Ni	8.0	30,000	0.17	6.5	11.4	12.5	12.9
MIM-Fe-50%Co	7.7	4,800	1.5	14	…….	…….	…….
MIM-Fe-3%Si	7.55	6,700	0.69	8.7	12.5	13.5	14.0
MIM-430L	7.60	5,000	0.67	7.3	9.75	10.5	11.0

1 oersted (Oe) = 79.55 ampere/meter (A/m)
1 kilogauss (kG) = 0.1 tesla (T)

Note: Parmatech does not warrant that these materials are fit for any particular application. All materials need to be tested by the customer to assure that they meet minimum performance criteria.

Materials & Properties

Typical Mechanical Properties of Parmatech MIM Alloys

Material Group	Alloy*	Yield Strength (MPa)	UTS (MPa)	Elongation (%)	Density (g/cm^3)	Hardness
Low Alloy & Alloy Steels	MIM-2200 (Fe-2%Ni) as-sintered	140	300	35	7.60	45 HRB
	MIM-2200 (Fe-2%Ni) Heat-treated**	200-600	380-650	2 to 20	7.60	>55 HRC (surface)
	MIM-2700 (Fe-7%Ni) as-sintered	300	390	25	7.60	70 HRB
	MIM-2700 (Fe-7%Ni) Heat-treated**	670	830	9	7.60	>55 HRC (surface)
	4140	1200	1550	4%	7.4	44 HRC
Stainless Steels	MIM-316L	180	500	50	7.80	67 HRB
	304 L	140	500	70	7.75	60 HRB
	MIM-17-4 PH As-sintered	730	900	6	7.60	25 HRC
	MIM-17-4 PH Heat-treated (H900)	1100	1200	5	7.60	36 HRC
	420 HIP + Heat Treated	1500	1800	3	7.70	52 HRC
Soft Magnetic Alloys	MIM-430L	240	410	25	7.50	65 HRB
	MIM-Fe-3%Si	360	530	30	7.50	80 HRB
	MIM-Fe-50%Ni	160	450	30	7.70	50 HRB
Controlled Expansion Alloy	F15	300	450	25	7.8	75 HRB
Other Alloys	ASTM B637	1150	1350	14	NA	NA

* Alloys with MIM prefix are also listed in the MPIF Standard 35 (2000 edition) Materials Standard for Metal Injection Molded Parts

** Depending on the type of heat treatment a range of mechanical properties can be obtained in MIM-2200 and MIM-2700

Note: Parmatech does not warrant that these materials are fit for any particular application. All materials need to be tested by the customer to assure that they meet minimum performance criteria.

Typical Mechanical Properties of Parmatech CIM Alloys

Material Group	Ceramic	Flexural Strength (MPa)	Compressive Strength (MPa)	Density (g/cm^3)	Color
Alumina	Al_2O_3 99.7%	310	3,200	>3.9	White
	Al_2O_3 99.7%	340	3,700	>3.98	White
	Polycrystalline ruby Al_2O_3 + Cr_2O_3	360	3,700	>3.9	Red
	Zirconia toughened Alumina (ZTA) 90% Al_2O_3 + 10% ZrO_2	500	2,000	>4.25	White
Zirconia	Zirconia ZrO_2	1,000	1,850	>6.0	Ivory or Black
	Zirconia alumina 80% ZrO_2 + 20% Al_2O_3	2,200	-	-	White
	ESD Zirconia ZrO_2 + doping	-	-	>6.0	Black

Note: Parmatech does not warrant that these materials are fit for any particular application. All materials need to be tested by the customer to assure that they meet minimum performance criteria.

Product Design Considerations

Design for Moldability
(Injection Molding Basics)

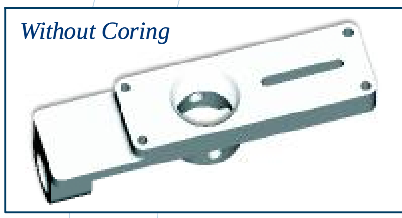
Parmatech will provide moldability feedback on every part submitted by the customer. In addition, we encourage potential customers to come and visit us for PIM seminars, a plant tour, design assistance and project reviews.

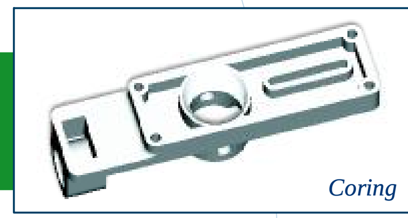
Proper PIM design begins with many of the same ideas used in plastic injection molding. If you are already familiar with the basic ideas behind traditional plastic injection molding design, you may prefer to skim this section.

Uniform Wall Thickness

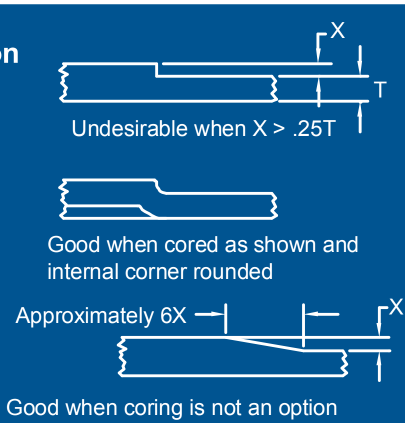
PIM parts should have uniform wall thickness whenever possible. By removing material in a design, you can minimize both mass and processing times, therefore reducing costs. Uniform walls also reduce sinks, which can affect part appearance and performance. If your current design does not have uniform wall thickness, you should use coring, as shown below.

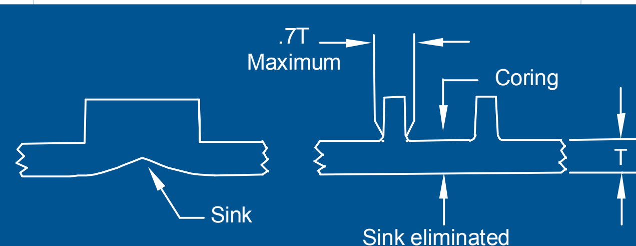
PIM can give you the design freedom possible in plastics with the strength of metal.





Transition





Gradual Transitions

Material flow is critical in PIM. The best designs avoid abrupt transitions between sections of a part. Gradual transitions help avoid molding stresses, which, in turn, lead to a more robust part.

Gating

Material enters the part cavity in the mold through a gate. A gate location can be critical because it remains as a visual imperfection. Gates are usually best placed on surfaces that are not cosmetic and do not involve a critical part characteristic.

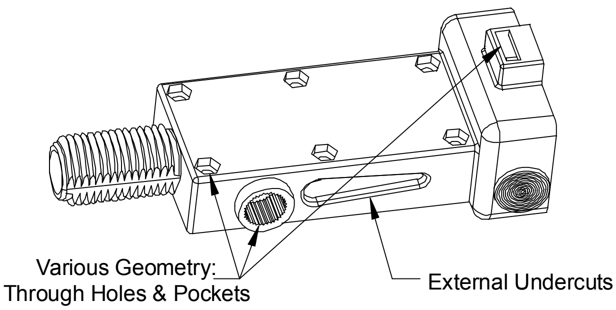
Parting Lines & Ejector Pins

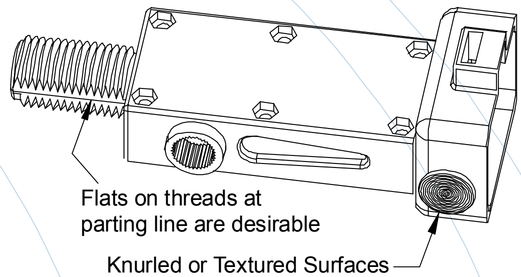
Cosmetic and other critical surfaces must be considered when determining locations for the parting line and ejector pins. Parting line refers to the location where the mold splits to release the green part. Ejector pins push the part out of the cavity.

Product Design Considerations

Draft

PIM typically requires a minimal draft of 1/2° to 1° per side, depending on the feature length and mold construction. This can even be reduced to zero draft for small features and strategic use of ejector pins.





Design Features

We have the ability to add your logo or part number, textured surface, or many other features a customer may desire. Holes, slots, undercuts and other such features are readily achievable and take great advantage of the PIM process.

Processing Considerations

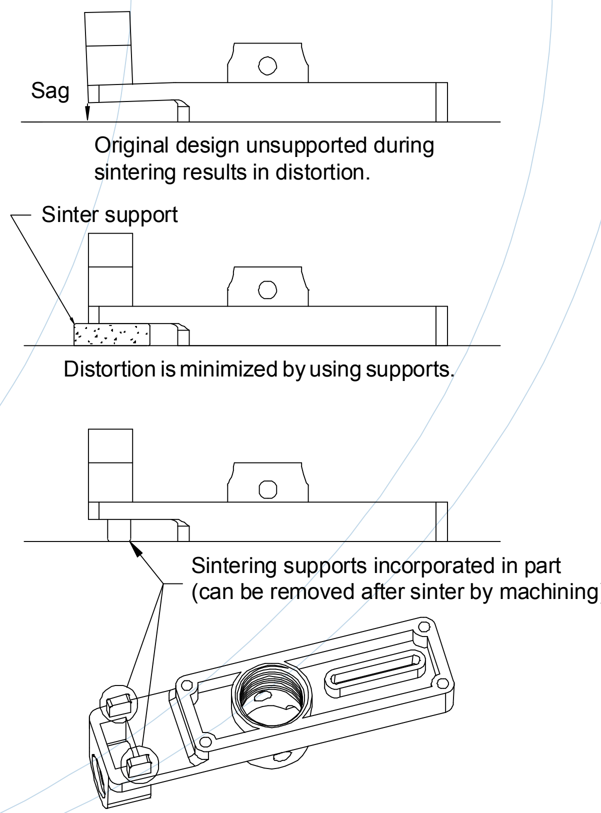
Beyond the injection molding step, a designer must be cognizant of the rest of the PIM process, and how a part's design can affect the ultimate outcome.

Internal Threads

Fixtures

Ceramic fixtures are used to support the parts in the sintering furnace. These can range from simple, flat plates to intricate, highly precise forms. In the sintering process, friction with sintering fixtures and gravity act on the part and, therefore, must be considered in the design of a PIM component.

PIM components that can be set on a flat surface tend to have the highest process capability, and minimal to no sintering fixture charges. Parts with unsupported sections may deflect during sintering, requiring secondary operations to bring features into tolerance. To avoid this, sintering fixtures or integral part features should be used, as shown to the right.



Product Design Considerations

Part Geometry

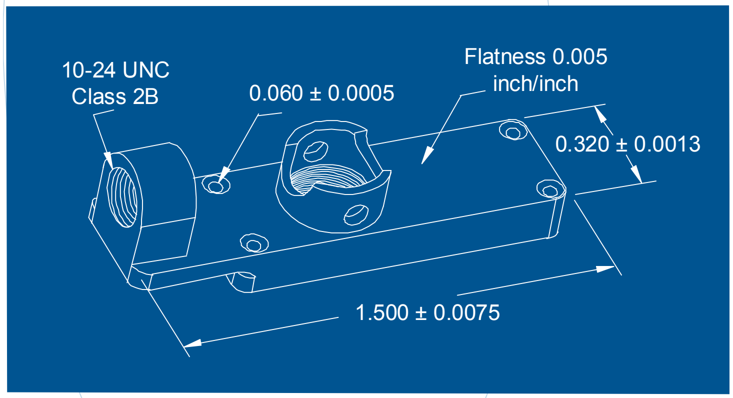
Part geometry is a key element of a successful PIM product. Some key characteristics to evaluate are:

Part Characteristic	Challenge	Solution
Large L/D Ratio	Parts may tend to distort.	Special molding techniques are required.
Large Footprint	More costly to produce in batch processing.	Utilize continuous processing. Minimize mass to reduce cycle times.
Thick Sections	Long processing times increase cost.	Use coring to reduce wall sections.
Heavy Parts	Material cost becomes larger portion of overall component cost.	Reduce mass through coring and redesign.

Secondary Operations

The goal of PIM is to make components net shape straight out of the sintering furnace. However, when an application demands tighter tolerances, secondary operations may be in order. We can utilize the same secondary operations that are possible for wrought or cast materials, such as:

- Machining
- Tapping
- Sizing
- Grinding
- Lapping
- And so on



Hot Isostatic Pressing (HIP) may also be used to achieve near 100% density in many PIM components.

Surface treatments that are used on wrought and cast materials are also available for PIM components, such as plating, black oxide, electropolishing, tumbling and many more.

Tolerancing

Part design greatly impacts process capability. From uneven wall sections to features that need support through sintering, there are specific factors that determine the tolerances possible on a part.

By working with you as early as possible in the PIM process, our sales and engineering staff can help you to match the process' capability to the tolerances needed to achieve required design function.

Without secondary operations, the general rule of thumb in PIM is that the process is capable of ±0.3% to ±0.5% of a given dimension; for example, 1.000 ± 0.005 inches or 25 ± 0.125 mm.

Product Design Considerations

Tool Philosophy

Parmatech utilizes an extensive network of tooling partners, both domestic and overseas. This network allows us the flexibility to meet cost and lead-time numbers that our customers demand. Our low-cost tooling strategy allows for a minimal up-front investment while our quick-turn efforts enable fast mold turnaround for customers with aggressive project timing.

Tool Design

Tool design and fabrication can be transparent or left up to Parmatech. In either case the tool remains the property of the customer. Complete tool design packages are always available for customer review and approval as needed.

Tooling Expertise

Parmatech's tooling approach is backed by years of PIM tool design experience and superior in-house tooling maintenance and repair. Our maintenance program contributes to the extended production life of our molds.

Production Tools

Production tools may be single or multiple cavity, depending on annual volume. They are constructed of premium-grade tool steels, with advanced cooling and hot runners, if required. Parmatech's proprietary feedstock formula enables tool lifetime to exceed 750,000 shots with some tools exceeding over 1 million shots!

www.parmatech.com

Notes

At Parmatech, we assess your needs, blend them with experience and innovation, and shape a solution that becomes reality.

Come visit us at Parmatech.com We're located just one hour north of San Francisco- in Wine Country and close to exceptional skiing and the Pacific Ocean.

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