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Metal injection molding (MIM) is a manufacturing process that can produce intricate geometries in metal parts, traditionally in larger quantities. MIM parts can have complex shapes, possess good strength and have excellent surface finishes, with mechanical properties similar to wrought materials.

MIM has been around for more than 25 years and is a multi-billion dollar industry with steady market growth of 15 percent globally, according to Powder Injection Moulding International. It is a crucial production process for many industries, including medical (components for medical devices), consumer electronics (keys, buttons and connectors for mobile devices), automotive (engine components, cams, pinions) and industrial manufacturing (valve components, fittings). Only recently have cost-effective options for prototyping and low-volume quick-turn MIM parts become available.

Many product designers and engineers don’t realize that MIM is a cost-effective option for prototyping and low-volume production. Proto Labs offers a solution with quick turnarounds (15 business days), low- to mid-volume production (25 to 5,000+) and low cost of entry (mold and sample parts for less than $5,000). Compared to alternative manufacturing processes for hard metals (e.g. machining), MIM can provide net-shape parts for a tenth of the price. Other contract MIM manufacturers have 30,000- to 50,000-part minimums and tooling can run $50,000 to $100,000 or more. Timing also is a drawback for other manufacturers, with an average of four months from project initiation until first parts available required.

**MIM Process**

The MIM process starts when metal powder suspended in a binder matrix (feedstock) is injected into a tool (mold) in a process very similar to plastic injection molding, creating a green part. The green part is then processed (debinded) to remove most of the binder, creating a brown part. The brown part is then processed (sintered) in a furnace to remove the remaining binder and to form a fully dense (typically 97 percent) metal part.

As with all manufacturing processes, proper part design is important for MIM parts. Many of the considerations for molding a plastic part also apply for molding a metal part — such as designing draft on features or radii on edges — to improve the moldability of a part. However, in the case of a metal injection molded part, greater attention needs to be paid towards the need for smooth material flow through the part (thus, greater importance to thick and thin transitions, and proper filleting of joints). This process also requires that the parts be supported throughout debinding and sintering.

After the part design is agreed upon, the MIM tool is designed. During this process, gates and vents are added to the part, and ejector pins (to push the finished part out of the tool) are selected and placed. The mold designer also adds side-actions for any undercuts. MIM tools are fabricated using a combination of CNC milling and electrical-discharge machining (EDM). After milling, the tool is polished by hand to customer specifications.

The finished tool is loaded into a metal injection molding press for green part production. A MIM press is nearly identical to a standard plastic injection-molding press, with a special screw and barrel designed to reduce separation of the binder and the metal powder during injection. Pellets of MIM feedstock are loaded into the hopper of the machine; they are then volumetrically metered into an injection barrel with a screw similar to an injection-molding press. Once the pellets are heated (through use of electric heaters and screw motion), the barrel is placed against the tool and the feedstock is injected. After solidification, the parts are ejected from the press and the cycle repeats.

After ejection, green parts are de-gated and placed on ceramic substrates (setters), which help retain the shape of the part throughout the debinding and sintering process. Pallets of green parts are loaded into a debind oven to remove

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**Advantages of MIM**

- Ability to produce high volumes of complex parts
- Relatively low production cost compared to several other metal-forming technologies
- If your part is destined for mass production in MIM, the ability to resolve manufacturability issues during the design stage, and before any actually molding has begun, is another big advantage
- Good surface finish
- Consistent and reliable
most of the binder that carries the metal powder through the injection-molding process; the binder is about 20 percent of the feedstock volume. The length of time required for debinding is a function of the thickest section of the part, as the binder must migrate all the way out of the part. At the end of the debinding process, the resulting brown part is approximately the same size as the green part, but only 80 percent dense. Just enough binder remains to keep the powder particles together, so the brown part is quite fragile.

Typically, pallets of parts are moved directly from the debind oven into a sintering furnace. The furnace precisely controls the temperature, cover gas and vacuum profile required to remove the remaining binder, and sinter the parts into the final product. During the furnace cycle, parts shrink about 20 percent into their final size.

After sintering, any secondary operations are performed and the parts are complete.

**MIM Materials**

A variety of metal powders are used for MIM. Stainless steels, the most common material, are used in just under half of all MIM applications. The 316L composition is frequently used because of its combined strength and corrosion resistance. Low-alloy steels are the second most prevalent group used in MIM, rounded out by iron-nickel alloys and specialty metals such as titanium and tungsten, although these are less common. Although aluminum feedstock is available, its use in MIM is rare. Because aluminum is a soft metal, other metalworking processes such as machining or casting tend to be more common. For hard metals such as stainless or low-alloy carbon steels, machining and casting become more problematic and MIM is the better process. Proto Labs currently uses 316L and 17-4PH stainless steels for MIM.

**MIM vs. Plastic Injection Molding**

Design considerations for MIM are very similar to those for standard injection-molded parts, with a few notable exceptions. For instance, the mass of MIM parts is typically less than 150 g, and the average MIM part is well below that. Metal injection molded parts also require relatively large gates compared to plastic injection-molded parts, due to the high metal content of the feedstock. Molds for MIM parts are typically polished to some degree to help prevent the parts from sticking in the mold during ejection.

Another difference between the two processes is MIM’s debinding and sintering steps, which require upfront design considerations. A MIM part shrinks by about 20 percent during sintering, which means MIM molds need to be oversized to account for this. Also, the MIM part becomes soft and responds to gravity during the sintering process. The polymer binder is burned away during sintering, essentially leaving a pile of very fine metal particles clinging together until they’re fused. During the sintering stage, the part becomes soft as the metal powders partially melt and join together. As a part shrinks, some of it slides on the supporting surface to reach the final position. An ideal radially symmetric part would shrink uniformly to the center, so the outside edges would move the most, the center would not move at all, and the center of mass would stay in the same spot during the process. Parts should be designed for proper support during the sintering process to ensure that they maintain their desired shape. The easiest parts to sinter have a common co-planar surface that can rest flat on a ceramic substrate or setter. When unsupported features are present, support often needs to be added through special fixturing to minimize or eliminate distortion of the part.

**MIM vs. Other Technologies**

As a general rule, compared to other technologies, MIM is more efficient and more economical at producing complex hard metal parts, especially as quantities increase. With MIM, it is often possible to eliminate multiple secondary machining operations, such as drilling, boring and grinding, by consolidating them into one single molding step. The following section compares several technologies to MIM.

**Machining.** Compared to machining, MIM offers a cost advantage for parts with more complex features, and that advantage increases as quantities increase. Many cost-effective MIM components have especially low mass. Because MIM is a molding process where minimal excess material needs to be removed, it saves time and material as compared to machining the part.

**Direct metal laser sintering (DMLS).** For additive manufacturing of metal, which is direct metal laser sintering, the process tends to be limited to small quantities. MIM is able to produce higher quantities of parts more quickly and becomes cost effective as volumes increase.
Investment casting. Investment casting is a labor intensive process that is better suited for producing small quantities of parts, and typically has a higher cost-per-part than metal injection molding. MIM also provides better surface finishes than investment casting, creating smoother parts with thinner walls.

Die casting. Die casting injects molten metal into a tool cavity. Because MIM parts are never molten and sintering takes place outside the tool that forms the desired shape, MIM parts can be made of materials with much higher melting points than die-cast parts. For lower-temperature metals such as aluminum and magnesium, die casting or thixomolding may be a better choice than metal injection molding. However, for steels and refractory metals, die casting is essentially impossible and MIM is the better process.

Metal injection molding offers a number of benefits that are unmatched by other metal-forming processes. Finished MIM parts have always had mechanical properties similar to wrought materials, but until now, the cost of entry has been prohibitive for many customers. The MIM process at Proto Labs is economical and allows parts to be delivered more quickly than traditional metal injection molding.

MIM Specifications at Proto Labs
- Maximum part size is approximately 4 in. by 4 in. by 4 in. (10.1 cm. by 10.1 cm. by 10.1 cm.)
- No deeper than 2 in. (5.1 cm.) from any parting line
- Maximum projected mold area of 10 sq. in. (64.5 sq. cm.)
- Maximum part volume of less than 1.25 cu. in. (20.48 cc.)
- Walls as thin as 0.040 in. (0.10 cm.) are possible, depending on the size of the wall and the location of adjacent thicker sections
- Wall thicknesses generally should not exceed 0.5 in. (1.27 cm.)