Vol. 11 No. 2 JUNE 2017

FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

Powder Injection Moulding International

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3DEO: Prototyping for MIM

Published by Inovar Communications Ltd

www.pim-international.com

Prototyping for Metal Injection Moulding: 3DEO's AM solution matches the density and chemistry of MIM parts

The nature of Metal Injection Moulding technology means that creating functional prototypes that match the density and chemistry of the final parts can be both expensive and time consuming, whilst machined or AM alternatives simply do not allow for a realistic assessment of how a component will function. In the following article 3DEO's Matt Sand presents a new service that promises to deliver prototype and low to medium volume runs of components that match the performance of MIM parts.

3DEO, Inc., based in Los Angeles, California, USA, has launched a novel, low-cost Additive Manufacturing technology that is uniquely suited to help accelerate component development in the Metal Injection Moulding industry. The technology was created in part to address the MIM market's need for a true prototyping technology. Existing technologies used for MIM prototyping often include subtractive manufacturing and laser sintering processes, but neither produce parts with material properties analogous to MIM. 3DEO's new AM process uses existing MIM infrastructure and materials to create prototype parts that are held to the same density and chemistry specifications as MIM parts, based on MPIF Standard 35. Leveraging MIM in this way has allowed the company to reduce final cost of parts by 60 to 80% when compared to conventional metal AM technologies.

According to PriceWaterhouse-Coopers, the single biggest barrier to implementing metal AM is cost. High-end metal AM machines cost on average over $700,000. Lower cost options are now coming to the market, but even the lowest cost machines are priced at $120,000. One of the biggest advantages of 3DEO's new process is the low cost of the machines. With laser sintering, for example, machine amortisation can be as much as 60% of the final part cost. 3DEO's machine cost is so low that its amortisation in part cost is negligible.

Beyond MIM, 3DEO is also able to produce complex metal parts for a wide variety of industrial customers. Since the process is not constrained by a mould, additional design freedom

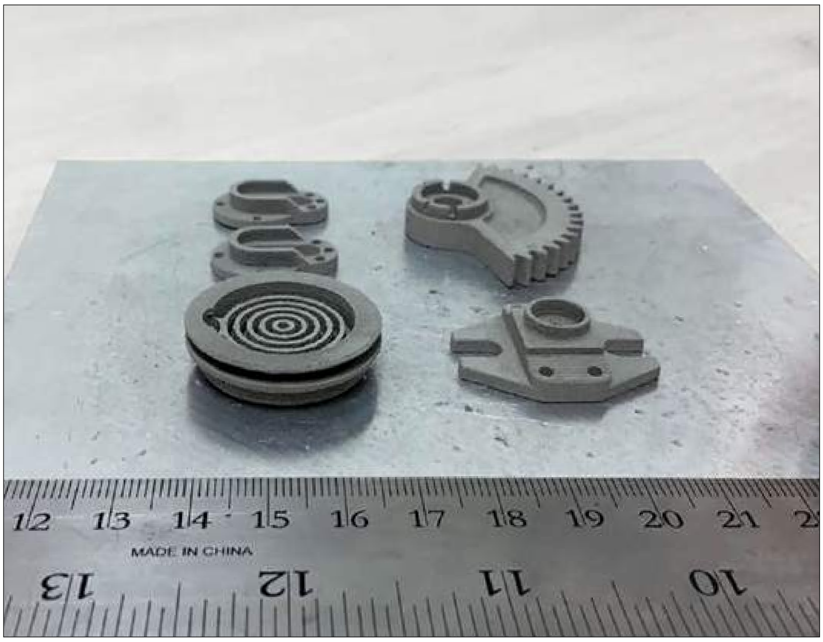

Fig. 1 Green parts after printing using 3DEO's process

Fig. 2 A selection of prototype MIM parts manufactured using 3DEO's Additive Manufacturing technology

and larger part size is possible. For example, conformal cooling channels in injection moulds are features that can only be achieved through Additive Manufacturing. Since 3DEO's technology has the design freedom of AM, there are many additional possibilities beyond MIM.

As part of its business strategy, 3DEO is not selling machines, but intends to become a parts supplier and subcontractor to other manufacturing companies. Given the low cost of 3DEO parts and established industry standards, the company is in a unique position to manufacture volumes of 100 to 10,000 pieces or more, something rarely seen in metal Additive Manufacturing.

Industry partnership with PolyAlloys

When launching the company, the 3DEO founding team quickly realised the importance of establishing strong industry connections. After exploring possible collaborations with a number of potential MIM companies in the United States, 3DEO partnered with PolyAlloys, also located in the Los Angeles area. PolyAlloys is a leading MIM manufacturer on the West Coast of the US and a division of PSM Industries, a Powder Metallurgy based parts production company with multiple facilities across the US. With its supportive team and available infrastructure, PolyAlloys has been a critical partner to 3DEO, incubating the new technology and helping the technical team understand the perspective of MIM manufacturers.

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The challenges facing MIM manufacturers

There are four main steps in MIM manufacturing: feedstock compounding, injection moulding, debinding and sintering. The homogeneous mixing of the metal powder and binding agent takes place in a large industrial mixer and creates the final pelletised feedstock. The feedstock is then injection moulded under elevated temperature and pressure to create what is known as the 'green part'. This green part is then debound via a solvent or through thermal processes, which leaves a 'brown part'. The final step is to place the brown part into an atmosphere-controlled furnace to sinter the respective metal base material. As the metal powder sinters in the furnace, the part begins to isotropically shrink 15-25% as it increases in density. After several hours in the furnace, the part is removed and cooled to its final finished state.

Due to the high cost of the mould and setup, MIM as a manufacturing process is only economical in very high volumes – typically tens or hundreds of thousands of pieces and higher, depending on complexity. This creates a number of problems for MIM manufacturers. Not only can moulds cost tens of thousands of dollars, but because of the complexity of their manufacture the first parts can take weeks or months to be delivered. Many prospective customers are simply not willing to make the capital or time investment before knowing that MIM parts will meet the fit and functional require-

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ments of their application. Given this dilemma, MIM prototype parts will help prospective customers evaluate MIM as a manufacturing option without incurring high entry costs or delays typically associated with MIM.

A further challenge for MIM manufacturers is the difficulty of building accurate moulds that will deliver net shape parts. Even for the most experienced practitioners, there are many unknowns associated with the moulding and sintering processes. When a mould does not work as intended, either the mould needs to be re-worked or the parts need to be fixed in secondary operations. Both options cut into a MIM manufacturer's bottom line. A proper MIM prototyping technology will enable MIM manufacturers to evaluate various geometric compensations, in order to drastically increase the accuracy of the mould and decrease the need for secondary operations.

Fig. 3 A gear (top) and heat sink (bottom) produced by 3DEO (Courtesy PolyAlloys)

Traditional MIM prototyping and its limitations

There are a number of prototyping options currently used by MIM manufacturers, but none are able to produce truly analogous MIM parts. One possibility is a temporary mould approximating the part, which can be used to deliver a limited number of MIM parts. Unfortunately, with the limited output and high time investment required to engineer and produce the mould, this can be a prohibitively expensive option.

Other metal part fabrication technologies have also been employed to make prototypes that customers can use for testing. These processes include both subtractive and additive manufacturing. The main issue with using either route is that the parts produced by these processes are not reflective of MIM part performance. Customers may be able to test the fit of the part, but the function of a MIM part can be drastically different compared to the function of a metal AM part. The same goes for parts made through CNC machining.

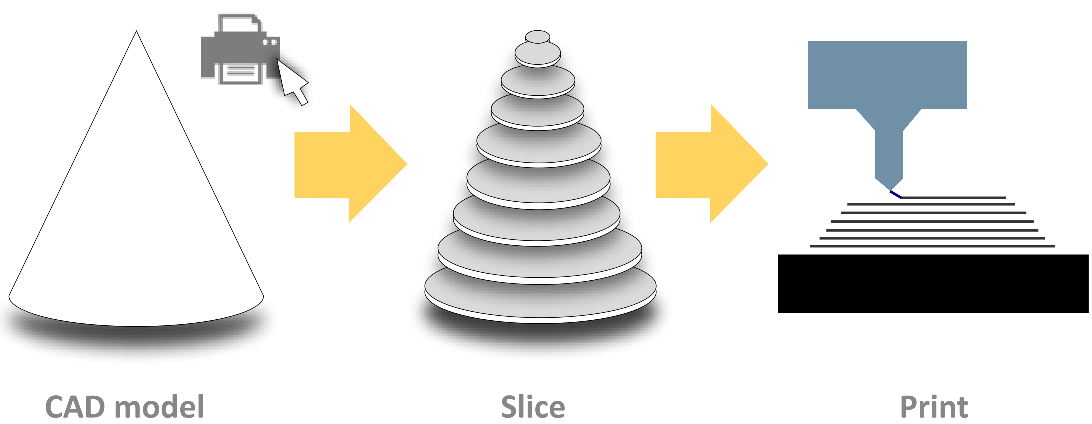

Fig. 4 The primary process steps in the conversion of a CAD object into an additively manufactured component

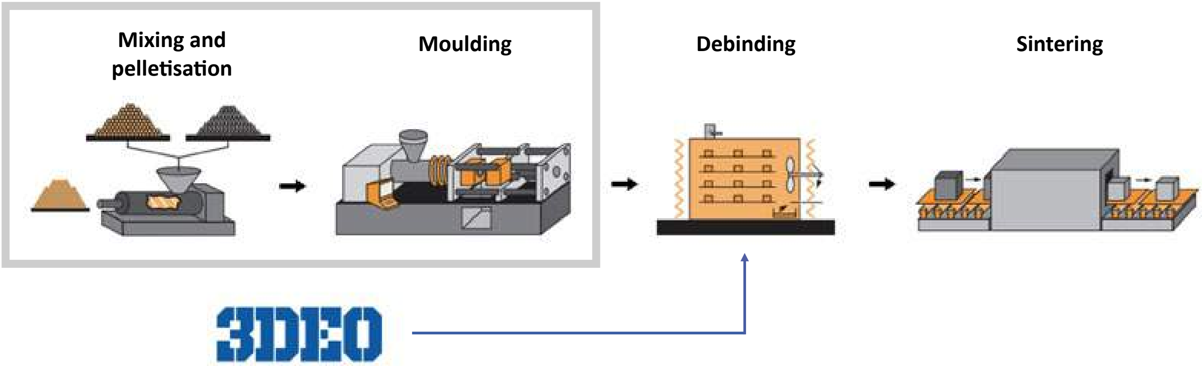

Fig. 5 The Metal Injection Moulding process. 3DEO's process shares the debinding and sintering steps as well as the metal powders

Customers correctly point out that while the dimensions of the part may be accurate, the performance of the parts will very likely be different. Ultimately, in the vast majority of cases, these subtractive and additive approximations of MIM parts will not help the customer evaluate MIM as a viable manufacturing option for high volume production. The MIM industry therefore needs the ability to create actual MIM parts in low volumes.

The opportunities presented by AM

Additive Manufacturing is a part fabrication process by which a real-world physical object is made from a three-dimensional digital model. This three-dimensional digital model is first created in a CAD software package and is then 'sliced' into two-dimensional layers (Fig. 4). Each of these layers is a thinly sliced horizontal cross-section of the eventual object. Each layer is manufactured in the AM process one at a time and stacked on top of previous layers. After all the 2D layers have been constructed, the final 3D part is complete.

There are a variety of existing metal AM processes, such as laser sintering and binder jetting, and each has its own advantages and disadvantages. In the end, AM is by no means a panacea for manufacturing. According to GE's Kirk Rogers, "Additive Manufacturing is not a replacement, but merely another method to complement other technologies on the factory floor." Regardless of the process, AM is a breakthrough manufacturing technology that will become industry standard and complementary to existing manufacturing processes.

There are a variety of benefits for AM. Design freedom is perhaps the main benefit, as parts that were previously impossible to build using traditional manufacturing techniques can be made with AM. Other benefits of AM include the elimination of tooling costs, immediate production on demand and drastically shorter lead times.

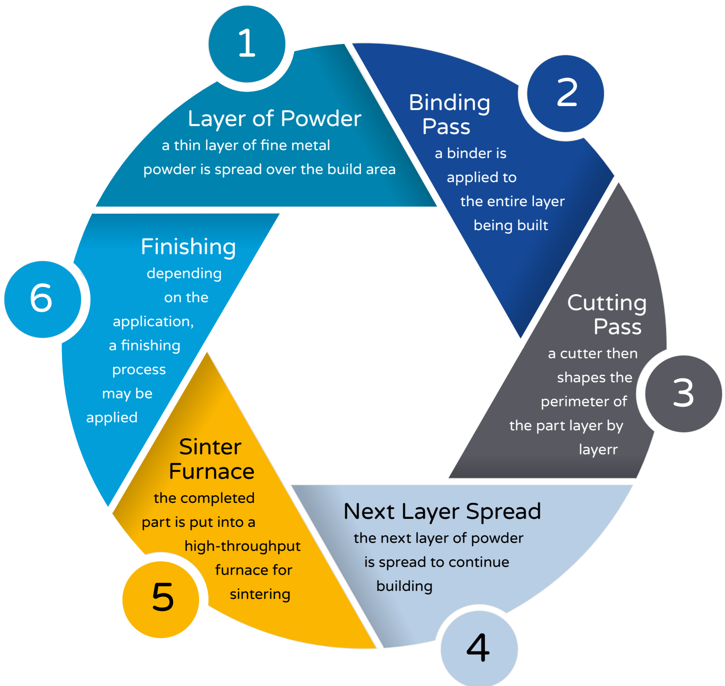

Fig. 6 Diagram of the 3DEO process steps

Creating the MIM analogue

3DEO set out to develop a rapid prototyping technique to produce truly analogous parts for the MIM

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industry. The team first approached this challenge by looking at the most widely recognised industry standard for MIM material properties, MPIF Standard 35. They evaluated whether green parts could be produced through Additive Manufacturing, as opposed to moulding, while still attempting to keep processing as close to MIM as possible.

This led to the creation of a process which replaces the first two steps of MIM (mixing and moulding, Fig. 5) with a single additive step, wherein a green part is created one layer at a time. This allows for green parts to be created with complex geometries and features associated with metal AM. The green part then undergoes the same sintering process as in traditional MIM. The result is a rapidly prototyped part that looks, feels and performs just like a MIM part.

There are six steps to 3DEO's Intelligent Layering® process, outlined below and in Fig. 6. The parts are built layer-by-layer in a 20 cm (8 in) by 20 cm bed of loose metal powder.

Step 1: Spread a layer of powder
The first step in the process is to spread a thin layer of spherical metal powder particles over the entire build platform. The layers can be very thin or relatively thick, depending on the geometry of the part and the features that are being built in that layer. The average layer thickness is 100 μm.

Step 2: Bind the layer
A low-cost spray head covers the entire layer with a proprietary binder. This binder is carefully applied to ensure it penetrates to an appropriate depth. The binder is cured so the part can then be defined in the next step.

Step 3: Cut the layer
A CNC end-mill is used to 'cut' the boundaries and internal features of the part. These cuts create channels that define the part as it is being built layer-by-layer (Fig. 7).

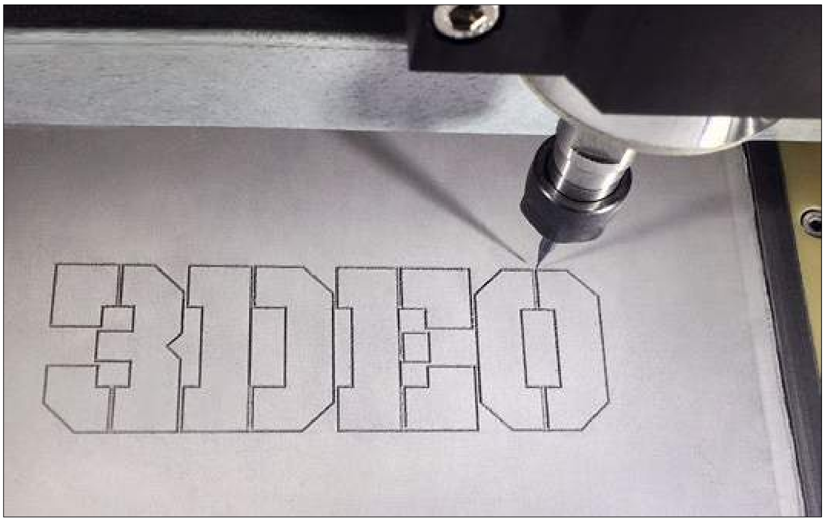

Fig. 7 The cutting set in action on a 3DEO machine

Step 4: Spread the next layer
Steps 1-3 are then repeated for every layer required to build the final green part. The height of the part determines how many layers need to be spread. For very tall parts, hundreds of layers may need to be spread. Most MIM parts require 50-100 layers.

Step 5: Sinter the green part
The green part created through this process is then inserted into a standard MIM debind and sinter furnace. Thermal debinding is, however, much more efficient due to the low binder content of 3DEO green parts.

Step 6: Finishing the part
Depending on the application and customer requirements, the parts can then be finished with a variety of options for secondary operations. Any secondary operations applied to MIM parts can also be applied to 3DEO's parts.

The metal powders used

Spherical fine MIM powders (D_{50} < 10 μm) are used in the 3DEO process. Currently, the company is making parts in 17-4PH. There are, however, many additional materials on the horizon. In theory, any spherical powder that is used in MIM today will also be able to be used in 3DEO's process. Future materials that are planned for development include:

- Inconel, nickel alloys
- Stainless steels
- F75 – cobalt chrome
- Titanium
- Tool steels
- Low alloy steels
- Soft magnetic alloys
- Controlled expansion alloys
- Tungsten carbide
- Tungsten heavy alloy
- Bronze, copper and brass

Part specifications

3DEO is currently working with MIM and non-MIM customers to further development this process. The parts being produced today meet the industry specifications of MPIF Standard 35, which is a chemistry and density specification.

- Component mass: 1 g to 2000 g
- Dimensions: 1 mm (0.08 in) to 200 mm (8 in)
- Tolerance: +/- 0.005 in/in
- Density: 97%
- Production Quantities: 10 to 10,000 units

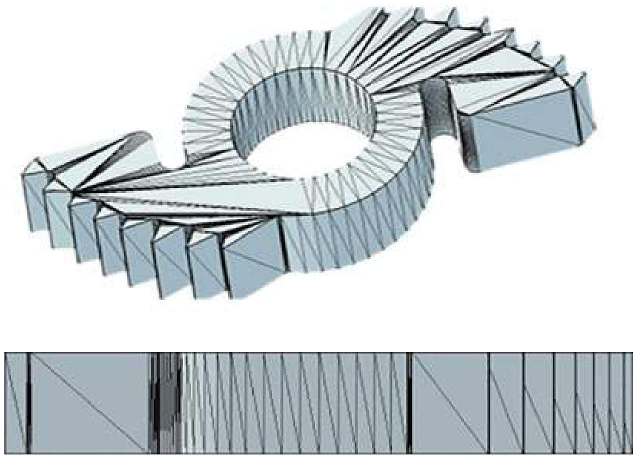

Fig. 8 An example of a 2.5D part

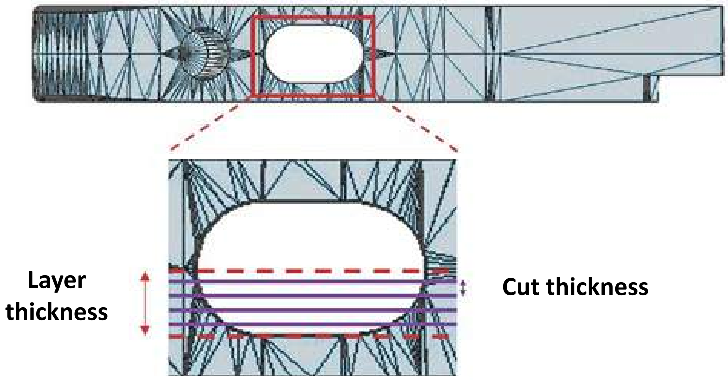

Fig. 9 Example of intra-layer cutting

3DEO's Intelligent Layering® process

There are several technical innovations in the Intelligent Layering® process used by 3DEO. The first is the ability to delay cutting on vertical sections so that multiple layers can be milled at the same time. This results in significant time savings and optimises the cutting process by only focusing on sections as needed. This is particularly useful on 2.5D parts (Fig. 8), or shape extrusions, where the CNC mill can cut down through the several layers at a time. Another highlight is intra-layer cutting, which is the ability to make multiple cuts within each individual layer to increase resolution (Fig. 9). In the 3DEO process, the cutting tool depth dictates the z-axis part resolution. For example, with each layer measuring 100 µm, this translates to cutting up to five times per layer at a thickness of 20 µm per cut. Finally, Intelligent Layering® also utilises a top down CNC process that allows for additional milling of the green part to smooth any layer lines and create high quality surface finish.

MIM prototype parts

3DEO is working with MIM manufacturers by providing prototype parts. The company states that for $2,500 it can deliver ten MIM prototype pieces with a fast ten-day turnaround. After this initial order, the per-part cost drops significantly and parts are quoted on a per-piece basis. Up to 10,000 pieces can be ordered. 3DEO intends to deliver prototype, pre-production and low-volume production orders to MIM manufacturers.

Conclusion

The strategic business advantages provided by 3DEO for the MIM industry arise from its ability to create truly analogous prototypes and low volume order fulfilment for existing customers. As a sales tool, the Intelligent Layering® system provides powerful value not only in fulfilling smaller orders, but also in the ability to reach the customer earlier in the sales process. This creates a new pipeline to grow business and funnel the higher quantity follow-on orders directly into the typical MIM process. Prototype parts can also help reduce operational costs by predicting shrinkage issues before investing in a production mould.

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