Whitepaper

e-Manufacturing Solutions

TOOLING APPLICATIONS WITH EOSINT M

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1. Introduction

EOSINT M systems manufacture solid metal parts by locally melting and resolidifying metal powder using a focussed laser beam, layer by layer, to build up the desired geometry fully automatically from 3D CAD data. Because metal powder is turned directly into solid metal parts, the production process is known as Direct Metal Laser-Sintering (DMLS). Depending on the powder material and processing parameters used, a wide range of part properties can be obtained, from controlled porosity for venting or filtering, up to fully dense structures with strength superior to cast or forged components. The layer-wise production enables even highly complex geometries to be manufactured directly, often eliminating the need for milling paths or EDM, and provides a unique freedom of design.
Tooling has been the main application of EOSINT M technology for at least the first decade since its commercial launch in 1995. This application is known as DirectTool due to the very short process chain, which enables tooling components to be manufactured in a very short time. For this reason, early users concentrated on "Rapid Tooling", i.e. using the technology to reduce the lead time for tooling. In the early years only relatively soft materials were available, so that mostly prototype tooling for plastics processing was produced, but with continual improvement of the technology the application range has extended to series production tooling for plastics and also tooling for metals processing. In addition to the "rapid" aspect, the focus has shifted more to using the unique geometric possibilities of the technology to design "advanced tooling", for example by integrating conformal cooling channels into tooling to improve quality and economics in production. Today EOSINT M tools are being used for example to injection mould millions of plastic parts and to die cast tens of thousands of metal parts.
This white paper gives an overview of how and why EOSINT M technology is used in tooling applications, focussing in particular on the most common application, injection moulding.

2. Reasons for applying DirectTool and application examples

2.1. Rapid Tooling for time and cost saving in toolmaking

Toolmaking is generally a costly and time-consuming activity, involving many process steps, expensive equipment and qualified personnel. Using conventional manufacturing technologies, even a relatively simple two-part (open-shut) injection mould typically requires CNC milling combined with Electrical Discharge Machining (EDM) to produce the moulding geometry of the cavity (injection side) and the core (ejector side). The milling may require removing large quantities of material from a metal block, and/or separate steps for rough and finish machining, and always requires the generation of CNC tool paths. Deep slots or sharp internal corners which cannot be milled require the production of EDM electrodes, each of which needs to be CNC machined and then positioned for eroding the relevant part of the tool. Tooling for more complex parts geometries often requires sliders, removable inserts or other features, which make the production even more complex and therefore costly and time-consuming. Therefore there is often a high motivation to apply methods which can save time and costs in tooling production. DMLS can greatly contribute to this by in many cases replacing milling and EDM steps. A good example of a relatively simple project is shown in Figure 1.

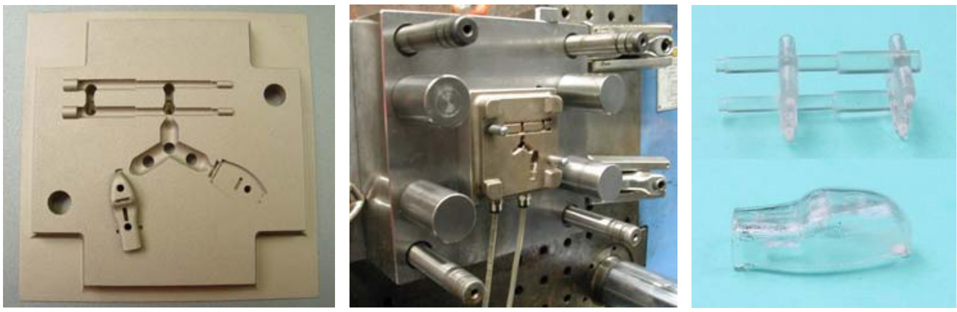

Figure 1: Series production of an LED light guide in polycarbonate.
Left: DirectTool insert.
Middle: completed injection mould.
Right: moulded parts.
Courtesy of EGi, PAKTO

In this case the requirement was for series production of two small plastic components in polycarbonate. Although fairly simple, conventional tooling would still have required EDM work. Using an EOSINT M 270 system, the core and cavity were built in just 5 hours 40 minutes. No post-machining was required, the finishing only involved shot-peening and slight manual touching up. The core and cavity were mounted directly onto the injection moulding machine, and production was started. Only six days were needed from project start to series production.

Figure 2 shows a much more complex project, which was performed by FIT GmbH.

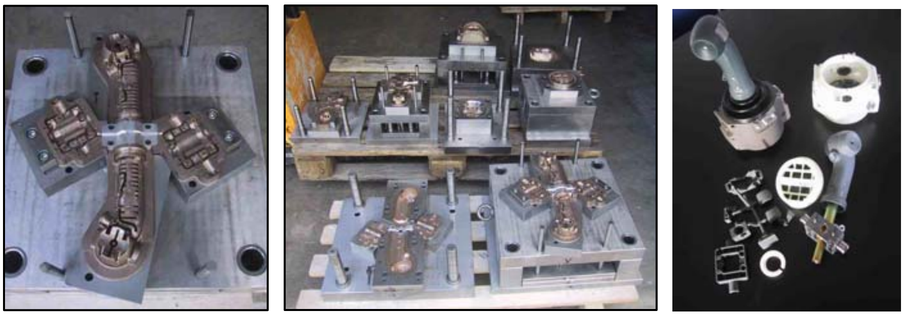

Figure 2: Series production of a joystick for a construction vehicle.
Left: injection mould (core side) for two components.
Middle: four completed tools.
Right: moulded components and assembled joystick.
Courtesy of FIT GmbH

It involved the series production of a joystick assembly for a construction vehicle. 5,000 assemblies were required, each comprising 14 injection moulded parts in PA6.6 GF. By combining DirectTool with just the minimum amount of machining, all 14 injection moulds were produced and the 5,000 sets moulded within nine weeks, including a three week delay due to design changes made by the customer, and modification of one tool to compensate for asymmetric shrinkage of a circular plastic part. The six working weeks compared to 16 weeks as the fastest delivery time quoted by suppliers using conventional technology, and in additional the tooling cost only around 50 percent of the next best offer. In other cases, DirectTool is used to produce tooling for highly intricate parts, which would otherwise involve extremely complex tool path generation and machining. Figure 3 shows two examples. In both cases, the series production tooling was made by DirectTool and required no post-machining. In the case of moulds for rubber or elastomers which include undercuts, these can be easily built by DirectTool without additional effort, whereas undercuts typically involve increased complexity for machining.
Although all the rapid tooling examples shown here are series production tools, the same methods are often also applied for prototype and bridge tooling.

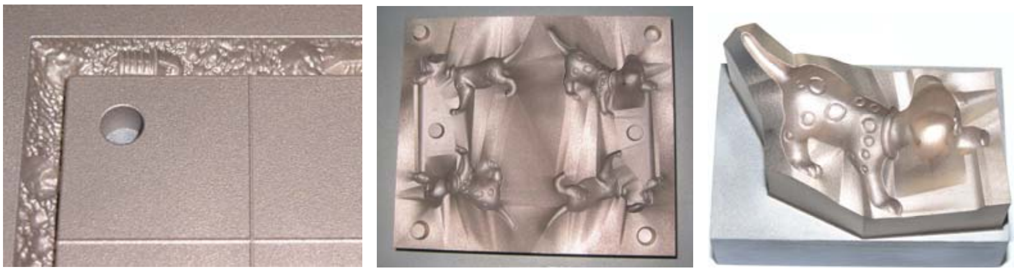

Figure 3: Examples of series production moulds with highly intricate form geometries.
(a) left: game board
(b) middle and right: promotional figures.
Courtesy of Games Workshop and LBC GmbH

2.2. Advanced Tooling for improving tool performance

The other main motivation for using DirectTool is to use the unique design possibilities of DMLS to improve the performance of tooling, i.e. to gain benefits in the production process after the tool has been manufactured. Of course this can in many cases be combined with cost and/or time saving during the tool production, but especially for large series production, any savings in the plastic part production can justify even increased costs in tool production.
The best known way of improving tool performance using DirectTool is by optimizing the design of cooling and/or tempering channels to enable lower and/or more uniform temperatures in the mould, or more rapid cooling and/or heating. This can reduce both cycle time and also scrap rates due to stresses and warpage. The result is typically increased productivity and reduced cost per part in production. With conventional machining, cooling channels are added into a tool by drilling, which restricts the cooling design to combinations of straight lines, which must all be accessible for drilling and must also avoid colliding with the forming surface, ejector pins etc. With DMLS, both the positions and shapes of cooling channels (or other elements) can be designed in a freeform way. When the channels are designed to follow the moulding surfaces of the tool, this is known as conformal cooling.

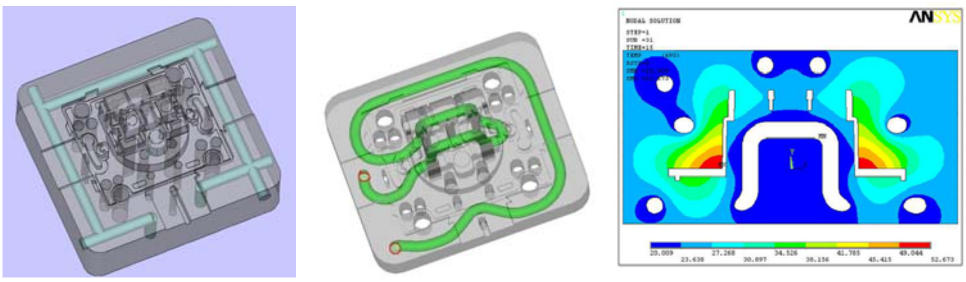

Figure 4: Electrical box.
Left: conventional drilled cooling channels.
Middle: optimized conformal cooling.
Right: Simulation of mould temperature.
Courtesy of PEP, Legrand

Many studies and examples have demonstrated the benefits of optimized cooling. Theoretical and practical investigations by PEP [1] have shown reductions of mould temperature by approx. 20°C (Fig. 4) and/or reduction of cycle time by 20 seconds. LBC has reported cycle time reductions of up to 60 percent and in one case a scrap rate reduction from 50 percent to zero by using DirectTool with optimized cooling [2].
The project shown in Figure 5 combined conformal cooling with a further technical benefit. The product in this case was a promotional (giveaway) golf ball, which had to be produced in large quantities at very low cost. The chosen production method was blow moulding of

extruded PP combined with elastomer injection. To avoid distortion, which was important to obtain spherical balls, a good venting of the mould during blow moulding was needed.

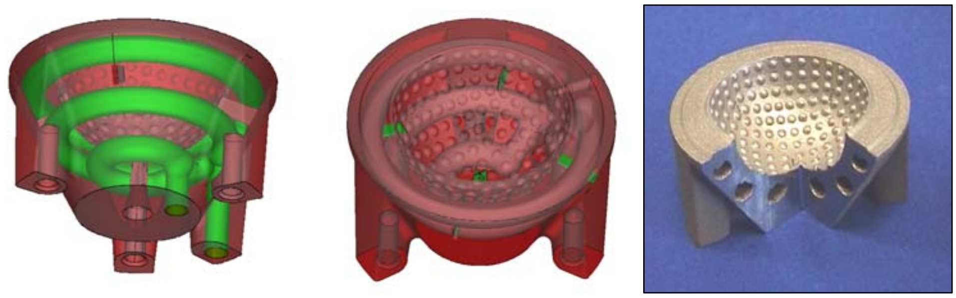

Figure 5: Blow mould for a golf ball.
Left: conformal cooling.
Middle: venting slits (in green).
Right: DirectTool mould cavity.
Courtesy of Es-Tec, DemoCenter.

This was achieved by integrating venting slits into the rear side of the mould cavities, and selecting DMLS material and processing parameters to produce a slightly porous surface layer to allow gas to escape into the vents without creating any visible surface marks. It can be seen that the volume of the mould half was also kept to a minimum, thereby minimizing build time and costs. Eight such mould halves were combined to make a four-cavity tool, which was used to produce more than 20 million golf balls. Only around 50 hours build time was required, and the conformal cooling increased productivity by 20 percent.

3. Methods for applying DirectTool in tooling processes

DirectTool can be applied in many different ways to achieve the benefits described above. A simple way is to build core and/or cavity inserts to fit into standard tool-frames or bolsters, in the same way that is commonly done with traditional machining. Often it is more effective, i.e. requires less effort, to mount the DirectTool core and/or cavity (including at least part of the build platform on which they have been built) directly onto the plates of the injection moulding machine, i.e. as "onserts" rather than inserts. This can be seen in Figure 1 and Figure 2.

Figure 6:
(a) left: machined aluminium tool and DMLS inserts.
(b) right: tool with DMLS sliders and guides in different materials.
Courtesy of General Pattern, Linear.

DMLS is often combined with other production methods for one tool, an approach which is often called hybrid tooling and which can be applied in many variations. For example if only one half of the tool has intricate geometry, like a mobile phone housing with a simple free-form outer (visible) surface but a complex rear (hidden) surface with ribs and clips, then it is often economical to machine the cavity (for the outer surface) whilst building the more complex core using DMLS. In other cases, only relatively small regions of a tool are so complex that they cannot be milled.

In such cases it can be sensible to build small inserts using DMLS and machining pockets in the main tool for these to fit into, either as fixed or loose inserts. An example with a machined aluminium tool is shown in Figure 6 (left picture), and a similar approach can also be used with cast epoxy tooling, in which case DMLS inserts are also used for any features such as thin walls where the epoxy would not be strong enough to resist the moulding forces [3]. DMLS can also be effectively used to build various other tooling elements. The example shown in Figure 6 (right picture) used DMLS for moulding cavities, sliding inserts and also the guides for the sliders. To prevent galling, different DMLS materials were used for elements which repeatedly slide over each other.

Intelligent tooling concepts also help a lot to apply optimized cooling in a cost-effective way. Figure 7 shows three examples. Figure 7 (a) shows a blow moulding tool for PE bottles. The cycle time and therefore production rate of such tools is typically limited by the cooling time for the necks of the bottles, which have the thickest cross-sections.

In the case shown, small DirectTool inserts with conformal cooling were built to extract the heat from these regions more quickly, and were integrated into a standard machined production tool. In this way the cycle time was reduced from 15 seconds to just 8-9 seconds, giving a productivity improvement of approximately 75 percent, with no loss of quality. 7(b) shows a cooling core designed to be inserted into the rear of the ejector side of a mould to remove heat from the injection area. This reduced the cycle time in production by two-thirds. 7(c) shows a core with integrated conformal cooling. The dome includes a spiral-shaped cooling channel, but the core has been designed so that the lower half can be easily machined.

In this way, the core was cost-effectively produced by machining the lower part, mounting it in an EOSINT M270 system and adding the top part by DMLS [2]. 0.3mm machining allowance was added for finish-machining of the outer surface.

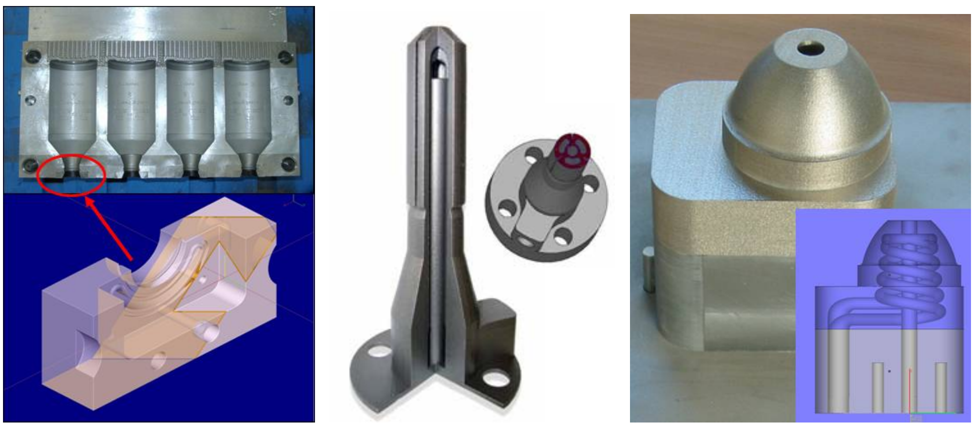

Figure 7: Cooled inserts for tooling.
(a) left: for the necks of bottles in a blow mould.
(b) middle: core for cooling the injection point of a mould.
(c) right: hybrid core with conformal cooling built on top of machined base.
Courtesy of SIG Blowtec, Es-Tec, DemoCenter, LBC.

DMLS is also sometimes used to implement design changes to existing tools or to repair worn or damaged tools.

4. Materials and building strategies

A variety of different metal materials are available for EOSINT M machines, and new materials are continuously being developed [4]. The most relevant material for series production tooling is a high-grade 18 Maraging 300 type steel (1.2709, X3NiCoMoTi18-9-5) which is marketed in powder form under the name EOS MaragingSteel MS1. This material is fully melted in the EOSINT M machine to produce fully dense parts with a hardness of 36 – 39 HRC as built, which can be easily post-hardened (6 hours at 490°C) to increase the hardness up to 53 – 55 HRC and produce an ultimate tensile strength of more than 1900 MPa. Tool components built in this material can be machined, eroded, polished etc. in a similar way to conventional tool steel materials. The middle and right examples of Figure 7 were built in EOS MaragingSteel MS1. In cases where lower strength and hardness are sufficient, often the material of choice for DirectTool is a proprietary bronze-nickel based alloy material called DirectMetal 20. This material has the advantage that it is very quick and easy both to build and to finish, and is therefore very popular for prototype tooling and low-volume production tooling. The high build speed is achieved partly by using processing parameters (laser scan speed etc.) which produce a partially porous structure inside the parts, whilst the outer surface region is built with higher density. The projects shown in Figure 1 through Figure 3 and Figure 6 were produced using this material. Other DMLS materials may also be useful for DirectTool applications in some cases, for example stainless steel materials are available which can be beneficial for moulding corrosive plastics. EOSINT M systems build parts on top of a metal plate called a build platform. When building mould cavities, the platform is typically integrated into the cavity design so that the DMLS geometry is melted directly onto the platform. Figure 8 (a) shows how multiple tool inserts can be built on one platform (these are components for the tool shown in Figure 6(b)). The individual inserts are cut out, typically by sawing or wire cutting, to produce inserts or onserts like those shown in Figure 1 and Figure 2. In cases where it is not convenient to integrate the platform, for example loose inserts or cooling pins, these are built on a support structure which attaches the DMLS geometry to the platform, and which is removed after building.

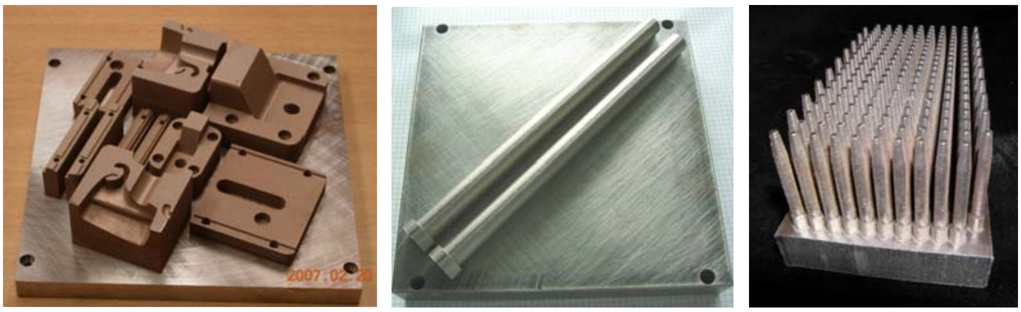

Figure 8:
(a) left: multiple tool elements built in one job in DirectMetal 20.
(b) middle: 305 mm long cores built in EOS MaragingSteel MS1 (1.2709).
(c) right: 200 cooling pins built in 1.2709 in 30 hours.
Courtesy of Linear, LBC.

An example is shown in Figure 8 (b), which also shows how long parts (in this case 305 mm) can be built lying down to save time. Figure 8 (c) shows a case where standardized cooling pins were being produced as a series product by EOSINT M. Here the most efficient and cost-effective method was to build large numbers of pins standing up – in this case 200 pins fitted on one half of a build platform and could be produced fully automatically (unmanned

operation) in just 30 hours. They can be efficiently separated from the build platform by wire cutting.
Aligning parts for post-machining can often be simply done using for example the side walls of the insert or other regular geometries. However, in more complex cases or where similar post-machining is often repeated, it can be beneficial to use a clamping and positioning system to save time.

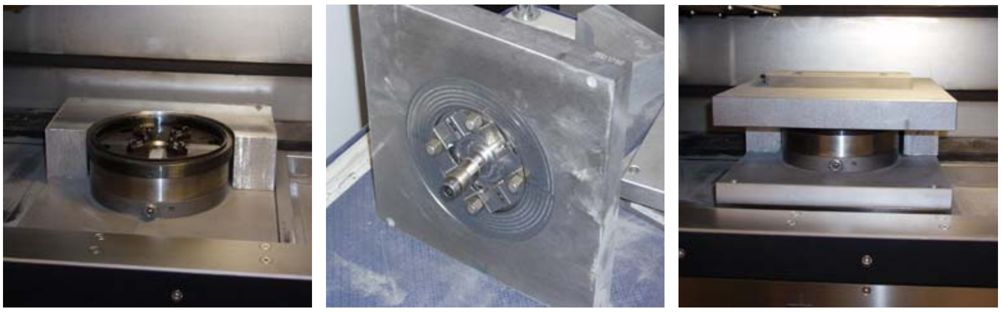

Figure 9: Use of an Erowa Powerchuck clamping system in an EOSINT M machine.
Left: chuck in machine.
Middle: palette with clamping pin.
Right: finished job ready for removal from machine.

Such a system based on the widely used Erowa Powerchuck 150 system is available as a commercial option for EOSINT M systems (see Figure 9), which is particularly relevant for users who have this system on other machining stations. But various other solutions have also been implemented, according to requirements and wishes of particular users. The process software of the EOSINT M system includes a feature to enable easy alignment of the machine coordinate system to any suitable mechanical reference.

5. Summary

The examples presented above are just a small selection from the very wide range of tooling applications which have already been published by EOSINT M users. Other documented tooling applications include for example vulcanization, wax injection for casting patterns, extrusion, thermofoam moulding, die casting, thixomoulding, sheet metal forming and stamping, glass forging and paper injection moulding. Also many other applications and methods of applying the technology can be considered. With the expansion in recent years from Rapid Tooling into series production tooling and advanced tooling, DMLS has established itself as a very versatile production method to complement traditional methods like CNC machining and EDM. Its ability to produce a wide range of geometries, including extremely intricate forms which are difficult to produce conventionally, rapidly and with very low effort, gives it unique advantages which have been driving the increase in the usage and acceptance of DirectTool.

References

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About the authors

Dr. Mike Shellabear graduated in mechanical engineering at Loughborough University of Technology, England, where he also gained his Ph.D in vibration analysis using laser interferometry. In 1991 he joined EOS, Germany, as Engineering Manager for 3D Optical Metrology, later taking over responsibility as Market Development Manager and then Assistant to the Management Board. Following that, he was appointed Product Manager for the Direct Metal Laser Sintering (DMLS) technology and became its Vice President in 2006. He has more than 15 years of experience in the Rapid Prototyping & Manufacturing industry.

Joseph Weilhammer, studied mechanical engineering at Technische Universität München, Germany, where he did his diploma thesis about post-processing methods for DMLS tools and parts for EOS GmbH. In 1996 he joined EOS and worked there in the development department for Metal-Laser-Sintering. Then he changed to Application department and in 2007 he became Product Manager for the Direct Metal Laser Sintering (DMLS) technology. He has more than 12 years of experience in the Rapid Prototyping & Manufacturing industry.