

DIE RECONFIGURATION AND RESTORATION USING LASER-BASED DEPOSITION

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Abstract

POM Company, Inc., located in Plymouth, Mich., has successfully commercialized the laser-based, free form fabrication process known as DMD,TM or Direct Metal Deposition. Since the company incorporated in 1998, POM has been directed towards the commercialization of the DMD process equipment, and the demonstration of value-added, cost-effective applications specific to the fabrication, repair and reconfiguration of plastic injection molds and die cast tooling. POM currently operates as a service bureau and original equipment manufacturer (OEM), providing engineering analysis, design and fabrication services, as well as the sale of DMD process equipment. An overview of the POM closed-loop, laser-based DMD process, available services and several case study applications are presented.

DMD Process Overview

The closed-loop DMD process includes a CO₂ laser and CNC-controlled overhead gantry to manipulate the focusing optics and powder feeder nozzle according to CAM tool path data associated with a solid-model CAD geometry. In contrast to the selective laser sintering (SLS) process, which utilizes a laser to sinter a variety of powder-based plastic materials to form 3-D shapes and prototype molds, the DMDTM process uses pure metal alloy powder to form 3-D metallic shapes.

Metallic powder, typically tool steel alloys (P20, S7, H13, H13+, 420SS or 420SS), copper alloys (CuCr, CuNi, CuSn or CuZn) or OFHC pure copper, is transported to the nozzle by an inert gas (Ar or ArHe) at a pre-defined rate from one of three on-board powder feeders. The metallic powder is added to a melt pool established by a focused laser beam, concentric to the nozzle. POM's patented closed-loop feedback control system maintains the size and shape of the melt pool, providing dimensional control and a very high quality, near-net shape deposition.

Moving the laser heat source and nozzle at a controlled rate according to the pre-defined CNC parameters and CAM path geometry results in a defined cooling rate ($10^3 \rightarrow 10^6$ degrees/sec). This provides uniform hardness, microstructure and isotropic material properties throughout the volume of deposition. The CNC tool paths and laser process parameters are tailored to achieve the desired cooling rate and as-deposited microstructure. Depositing tool steel alloys using the DMDTM process typically results in an "as-quenched", fully hardened, martensitic microstructure with very fine and uniform distribution of intermetallic carbide particles. This provides improved mechanical properties (toughness and yield strength) as compared to those of commercially available wrought alloys. Akin to that of laser welding, the heat affected zone (HAZ) associated with the additive metal deposition is very shallow (typically

0.015”), and void of the typical “sink” type defects associated with conventional high-temperature welding processes.

The as-deposited material is typically tempered, using conventional thermal heat treat practice or a defocused laser beam. Laser tempering provides the benefit of “color matching” the microstructure of the deposition to that of the substrate material. It also reduces processing time and costs associated with disassembly, pre-heat and post-heat treatment processes.

From an engineering perspective, a customer typically transmits a 3-D solid model of the mold or die to the POM ftp website (www.pom.net) for feasibility evaluation and quoting. A solid model associated with the desired deposition volume is created and sliced into layers, which coincide with the height or thickness of layered deposition process (typically 0.005” -> 0.015” thick). CNC tool paths, identical to those used for CNC machining, are then generated for each layer using traditional CAM software (SDRC-Ideas). The CAM output is then post-processed, using POM proprietary software. This software basically inverts the CAM file and imbeds laser and powder commands specific to the application requirements. The post-processed file is then downloaded to the DMD™ machine for processing.

A 3-D shape is fabricated on a layer-by-layer basis. It is identical to that of the CAD model used to generate the tool paths, by depositing “roads” which are approximately 0.040” wide. The deposition rates, specific to each material, range between 0.50 in³/hr and 0.75 in³/hr. The relatively low deposition rate, and low heat input (Btu/hr) associated with the process, provide conditions that are ideally suited for additive metal repairs and fabrication of composite material molds and dies.

The case study applications presented illustrate the commercial viability of the DMD™ process. These case studies include the deposition several tool steel alloys associated with die restoration, mold reconfiguration, repair of plastic injection molds and die cast tooling. Each application demonstrates how this technology can reduce tooling costs and improve tooling lead times.

Case Study Applications

Die Cast Tool Restoration – The functional use of die cast tooling (die life) is commonly limited by the initiation and growth of cracks due to “heat checking.” Heat checking results in brittle failure or the entrance of cooling water into the die cavity. This type of failure is commonly known to result from thermal fatigue imposed by high thermal gradients, thermal cycling and the reduction in mechanical properties (impact strength and yield strength) at elevated operating temperatures. It is not surprising then that heat checking type failures are often observed in areas of the die that are difficult to cool (elevated die temperature), subjected to high metal velocities (elevated die temperature), and/or adjacent to a water line (thermal gradient).

A significant portion of the cost associated with a die cast part is related to tooling cost and die life. Typically, the cost of the tooling is amortized over the anticipated life of the die and

added to the piece part price. Due to the lack of an acceptable restoration process, dies are frequently comprised of inserts, which are replaced throughout the life of the die. In many cases, the part design or die design does not permit use of replaceable inserts as failure takes place in the die block, requiring purchase of new tooling.

In most cases, the heat checked or eroded areas of a tool are confined to localized areas, which are difficult to cool and subjected to high thermal gradients. The DMD™ process offers significant cost savings potential associated with restoration of heat checked and eroded die surfaces. DMD™ affords this opportunity because it can restore existing tooling, rather than requiring tooling to be replaced...and, at a fraction of the cost.

Case Study #1

The ingate and runner areas associated with four severely heat checked H13 die cast inserts were restored by POM using the DMD™ process. Further production use and related thermal cycling would have resulted in replacement of the inserts due to catastrophic failure or propagation of the heat check induced cracks into the water line.

The DMD™ laser-based restoration solution included:

- Removal of approximately 4 in³ of thermally fatigued, heat checked material from the runner area of each of the four inserts. This was accomplished using conventional CNC machining.
- Deposition of H13 tool steel, restoring the heat checked surfaces of two inserts
- Deposition of POM proprietary H13+ alloy, which possesses improved mechanical properties at elevated temperatures, was deposited in the runner area of two inserts.
- Thermal tempering.
- CNC machining of the inserts per the original CAD geometry.

The four-cavity mold is currently being used in production. The results of the on-going production trial, which commenced in July 2000, will provide valuable insight on the use of the DMD™ process to restore heat checked die surface. It will also serve as a comparative evaluation of two-alloy compositions, relative to the potential increase in die life. The benefits this company has realized already include a significant reduction in tooling costs realized through increased die life through restoration vs. replacement of die cast tooling.



Figure 1 – Pre-machined, heat checked runner area



Figure 2 – DMD-restored insert

Reconfigurable Tooling – The product development cycle associated with plastic injection molded parts historically includes the procurement and fabrication of “soft tools” to produce prototype parts. This is followed by the design and build of production tools, once the product design is finalized. Until recently, “soft tooling” was comprised of aluminum, which can be CNC machined at high feed rates and easily reworked to accommodate engineering changes during the product development cycle.

In recent years, due to the advances in high-speed CNC machining, an increased percentage of soft tools are fabricated using free-machining, low-carbon steel. Fabrication of low-carbon steel prototype tooling maintains the low cost and short lead-time benefits associated with aluminum tooling. Simultaneously, it provides the molder with inset associated with the thermal and filling aspects of the molding process due to the similar thermal conductivity of steel alloys. Although significant improvements have been made in recent years, the overall cost and lead-time associated with two tooling development programs has not been addressed.

The DMD™ laser-based deposition process provides the capability to fabricate composite material molds comprised of low carbon steel substrate and tool steel mold surfaces. This combination offers the low cost and compressed lead-time benefits of low-alloy steel tooling, while providing hardened tool steel mold surfaces required for production use. In essence, the reconfigured prototype tool becomes the production tool...at a fraction of the cost and lead-time required to design and build a prototype tool and a production tool.

Case Study #2

POM recently reconfigured an obsolete two-cavity, low carbon steel prototype tool used for production of automotive body side moldings. The tool reconfiguration process included:

- Offsetting the CAD geometry associated with the new part geometry by 0.060”.
- Overlaying the existing mold geometry with that of the new part.
- Generation of tool paths.
- CNC machining of the obsolete mold surface.
- Laser-based deposition of 0.090” thick layer of P20 tool steel over the 1025 steel substrate.
- Thermal tempering of the P20 deposition.
- Re-machining and benching of the styling surface.

Prototype parts were submitted in 35 days, at a fraction of the cost and lead-time it takes to design and build a new prototype tool. The typical lead-time associated with the construction of conventional prototype tooling is 12 to 14 weeks.

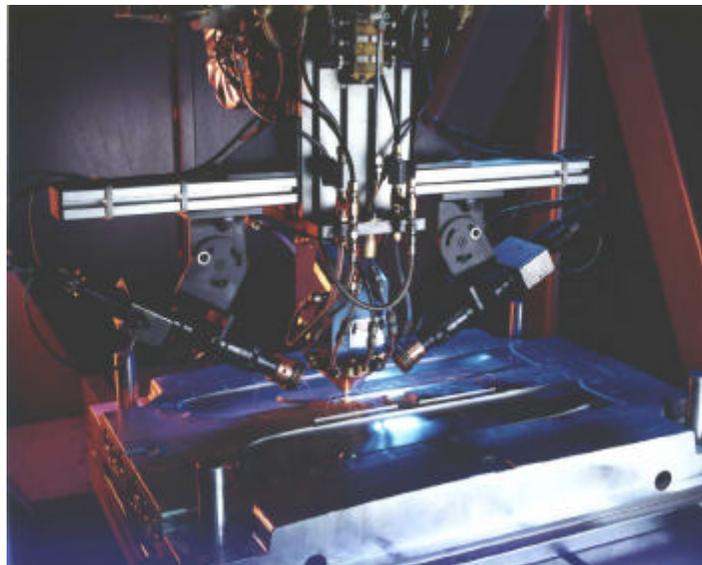


Figure #3 – Pre-machined 1025 LCS
(laser clad surface) of body
side molding prototype tool

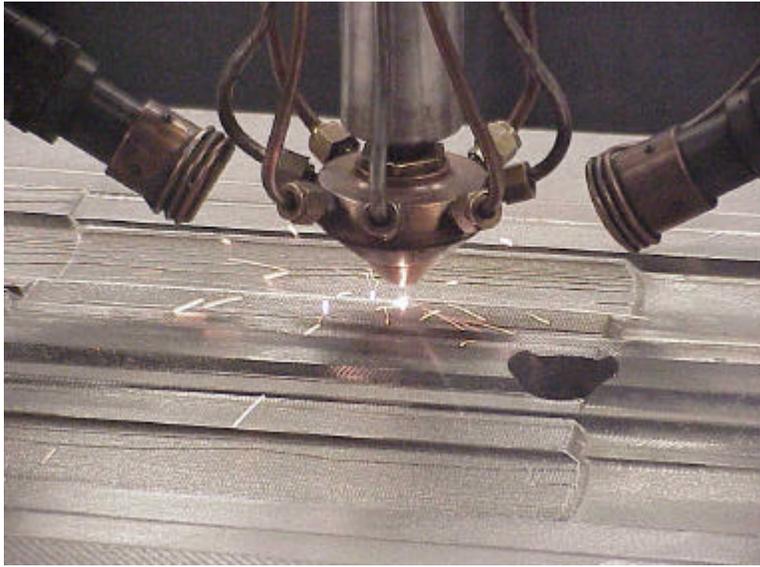


Figure #4 0.090" P20 tool steel styling surface

Additive Metal Deposition – All too often, machining errors or last-minute engineering changes jeopardize on-time delivery of the tool and potentially impact the introduction date of a new product. Frequently, new tooling is “welded” using conventional processes and the part quality standard is compromised until a replacement cavity can be manufactured.

The high-temperatures associated with conventional welding processes impose variable cooling rates throughout the relatively large heat affected zone (HAZ). This results in composite microstructure comprised of martensite, bainite and retained austenite. In addition, due to the lack of adequate shielding and the presence of deoxidizing elements (Al, Ti & Si) in the weld rod, the weld deposition often includes a high percentage of oxide inclusions and intermetallic compounds. This reduces mechanical properties, hard spots and porosity. In an effort to minimize weld stresses developed as a result of solidification shrinkage, and to normalize the variation in cooling rate, conventional tool steel welding procedures typically specify pre-heat and post-heat treatment of the mold or die. “Color match” weld procedures specify post-weld solution heat treatment and tempering. These procedures often induce dimensional distortion, cracking and “sink” type defects at the weld interface, resulting from the transformation of the composite microstructure to martensite during post-weld heat treatment.

The DMD™ process is ideally suited for additive metal deposition applications because it uses pure alloy powder (void of deoxidizing elements) and low heat input specific to the laser-based deposition process. The as-deposited martensitic structure, shallow heat-affected zone and laser tempering provides a deposition that is identical to that of the parent material, and does not require preheat and post weld heat treatment.

Case Study #3

POM recently restored an S7 tool steel production mold insert used in the production of an automotive thermostat manifold. The 1.8 in³ 3-D section, which had broken away from the solid during production use, was redeposited using the DMD™ process. The tool reconfiguration process included:

- Pre-DMD machining of the irregular surface.
- Generation of tool paths from the customer-supplied CAD geometry.
- S-7 tool steel deposition (restoration) of the 3-D shape.
- Solution heat treatment & tempering.
- EDM finishing of the near-net shape deposition.

The restored mold was returned to the customer in three days for final finishing and was back in production in a total of five days. All was accomplished at a fraction of the cost and lead-time associated with the build of a new tool insert. Due to the lack of a back-up tool, which is not uncommon in the molding industry, the customer ran one of its two-cavity molds, 24 hours/day to supply parts to the customer during five-day tool repair process. The typical lead-time associated with the construction of replacement tooling at premium rates would have been eight weeks.



Figure #5 - S7 thermostat mold with a broken core (see lower right)



Figure #6 - Restored S7 thermostat mold (see rebuilt core in lower right)

Case Study #4

A late engineering change reduced a wall stock associated with an electrical connector housing. This created the need to add 0.035” of H13 tool steel to the surface 10 new hardened mold inserts (Rc 48).

The tool reconfiguration process included:

- Fabrication of copper masks to prevent the possibility of tool damage due to stray laser reflections.
- Generation of tool paths from the customer-supplied CAD geometry.
- H13 tool steel additive metal deposition to the surface of the mold.
- Laser tempering.
- EDM finishing of the near-net shape deposition .

The stock added to the finished and hardened production inserts provided significant cost savings to the customer. It also drastically reduced the time required to remanufacture 10 new inserts to accommodate the engineering change.

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