A Study Report on Rapid Tooling Process

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Abstract: - Rapid Tooling (RT) describes a process that is the result of combining Rapid Prototyping techniques with conventional tooling practices to produce a mold quickly or parts of a functional model from CAD data in less time and lower cost relative to traditional machining methods. Rapid Tooling can act as a production injection molded parts. Rapid Tooling (RT) typically, either uses a Rapid Prototyping (RP) model as a pattern or uses the Rapid Prototyping process directly to fabricate a tool for a limited volume of prototypes. Expensive tooling cost can be well justified just when the production quantity is massive. Actually the way to produce tooling quicker and more economically, especially for small quantity manufacturing becomes a significant question. Additionally, in the product development cycle, requires always some intermediate tooling to produce a small quantity of prototypes or functional tests, samples for marketing, evaluation purpose, or production process design. RT becomes more and more important to nowadays manufacturing industry. The main advantages are tooling time is much shorter than for a conventional tool. Time to first article can be less than one-fifth that of conventional tooling; tooling cost is much less than for a conventional tool. Cost can be below five percent of conventional tooling cost. The main challenges are tool life is less than for conventional tools and tolerances are wider than for conventional tools.

I. INTRODUCTION

Rapid tooling is an application of Rapid Prototyping that refers to using rapid prototyping technologies to produce prototyping or preproduction tools or molds. This automatic building typically reduces the amount of time needed to produce such tools by less than 20% of the time needed in the typical manufacturing process. The cost of building tools in this manner can be significantly less costly than production tooling. However, these tools tend to have a shorter lifespan.

Rapid tooling is appropriate for difficult and complex geometries more easily handled by transferring the design of the tool directly from a design software application directly to a manufacturing process or technique. This process is especially suitable for simple tools due to the ability to more accurately represent such tools programmatically.

There are two types of rapid tooling are indirect and direct.

In Indirect Tooling, models created from the process are used as patterns to create the molds. These indirect tooling processes include:

Vacuum Casting: The model is suspended in a vat of liquid silicone or room temperature vulcanizing (RTV) rubber. The mold that forms around the model as the rubber hardens is removed by cutting it in half and the model is removed leaving a cavity. . Tools produced by this process have very good accuracy. Epoxy and urethane materials can be poured into the cavity to product prototype parts.

Sand Casting: A sand mold is built by packing a sand mixture around the model to form the mold cavity and pouring a casting liquid into the cavity. This technique is typically used for prototype or preproduction metal parts. When very limited quantities are needed the parts can also be used for production parts.

Investment Casting: A ceramic shell is formed around the prototype wax model. The model must not expand during the autoclave process which hardens the shell in order to form the mold. The wax model is removed by melting leaving a cavity as the tool. Molten metal is poured in the cavity to form the part.

Injection Molding: A mold is formed by encapsulating the model with a composite or aluminum filled epoxy material to form the tooling. The resulting tooling is used in the injection molding process.

In Direct Tooling, the tooling is produced directly from the prototyping process. Some available techniques for this process include:

Rapid Tool: A metal mold is created using the SLS technology that can produce up to 50,000 injection moldings.

Laser-Engineered Net Shaping (LENS): Creates metal tools from CAD data by using a laser beam to melt the area of the tool where material is to be added. The tool is built layer by layer by adding the desired material to the melted area. This process is only applicable to tools with simple, uniform cross sections.

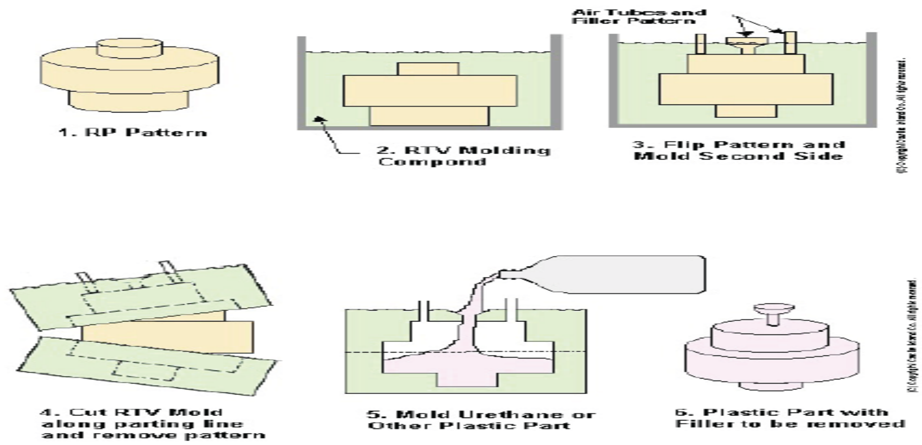
Sand Molding: Sand molds are constructed directly from CAD data.

Indirect Rapid Tooling – Silicone rubber tooling Silicone Rubber Tooling

This is a standard method of making small quantities of polymer parts. Any rapid prototyping generated part can be used as a pattern to make silicone rubber tooling. These tools can be used to mould small to medium quantities of parts in a large variety of urethane, epoxy or other polymers. Some of these polymers have properties which emulate particular engineering thermoplastics, and it's also possible to fill them for added strength. The method doesn't produce a part which is identical to an injection molded part, however, because the conditions of manufacture aren't the same. Injection molded parts may have functionally-important anisotropic mechanical properties that depend on how the material flows in the mould and cools, for example. Nevertheless, silicone rubber tooling is inexpensive, offers good accuracy and finish, and the parts produced are often adequate for prototypes or small production runs. The materials are often used in a natural state, but painting and other secondary operations can result in parts that are very attractive.

Silicone tools can typically be used to mold several parts before it becomes necessary to replace them. The number depends on accuracy and finish requirements and the specific geometry of the item produced. It may be possible to make many dozens of simple or non-critical parts from a single silicone rubber mold, but ten to twenty is typical if the parts are more complex. Wear of the mold occurs due to the exothermic and reactive nature of the polymers, and because of the necessity to mechanically deform the mold to remove the part. It may often be necessary to replace the RP generated pattern as well, depending on the number of molds to be made and similar accuracy and geometric considerations.

The process is carried out by placing the RP-generated pattern in a frame, usually made of wood. The pattern itself usually must undergo secondary operations to bring it to the desired state of accuracy and finish before it can be used. See the section on RP-generated patterns. Silicone rubber room temperature vulcanizing (RTV) molding compound is then poured around the pattern. It may be necessary to apply a vacuum to the assembly to pull air bubbles out of the rubber and insure fidelity to the pattern. Once the rubber has solidified, the pattern is removed and the mold is ready to be used.



Indirect Rapid Tooling – Aluminum filled Epoxy tooling

Aluminum-filled epoxy tooling is a good choice for short prototype or production runs for applications that require an engineering thermoplastic as a final material. It can be thought of as one step up from silicone rubber tooling, and while it's fabrication is similar in concept, in practice it's more complicated and expensive. Molds made in this way are used in injection molding machinery, but as with RTV rubber molds, the parts fabricated won't be identical to those created in a high volume mold. Cycle time must be considerably longer due to the poorer thermal conductivity of the material compared to metal, and lower pressures must be used to accommodate its lower strength. The process works best for relatively simple shapes. Tool life is Adequate for anywhere from 50 to 1000 parts, depending on requirements.

The following is a somewhat simplified description of the process, which has much in common with that used to fabricate an RTV rubber mold:

An RP-generated pattern is embedded in a wooden frame along a parting line. Aluminum-filled epoxy is poured around it to create the first half of the mold. It's usually necessary to secure the positioning of the pattern with specially-fabricated wooden supports, and often specially-machined metal inserts are placed in areas of the mold that might need strengthening. The parting line might also be a fairly complex geometry rather than just a simple plane, requiring additional fabrication steps. After the mixture hardens, the entire assembly is inverted and the second half of the mold is cast against the first. After the second half of the mold is completed, the pattern is removed.

Aluminum-filled epoxy molds are typically used in a mold frame and water cooling lines can also be included during the fabrication process.

Indirect Rapid tooling – Spray Metal tooling

Spray metal tooling is made in a similar fashion to aluminum-filled epoxy tooling. In this case, an epoxy or low melting temperature metal alloy tool is prepared by casting this material against an RP generated pattern. A thin metal coating is then arc-sprayed on the resultant mold's working surface to give it greater strength. Tool life is about the same as for aluminum-filled epoxy, but the method can accommodate larger parts.

Indirect Rapid tooling – Cast Kirk site tooling

Kirk site tooling is advantageous for more complex geometries, but it's generally less accurate and more expensive than aluminum-filled epoxy, or spray metal tooling. Kirk site is a zinc-based alloy and the tool making process also starts with an RP-generated pattern, but has more transfer steps than either of those methods. Kirk site tools have about the same life as spray metal or aluminum-filled epoxy tools.

Indirect Rapid Tooling – 3D Keltool tooling 3D Keltool T M

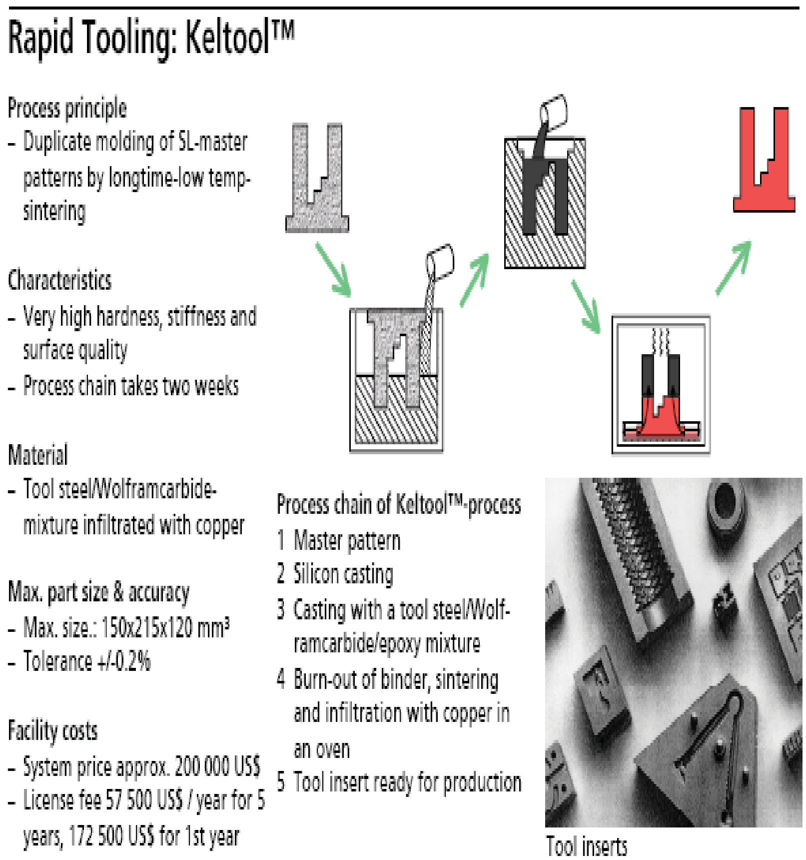
3D KeltoolTM is a method of creating a moderate to high volume tool. The process was developed Over twenty five years ago by 3M, but languished for years until the ability to make accurate Patterns economically by RP came into being. It's presently owned and licensed by 3D Systems, but is now only available from a handful of licensees in the US and Europe.

Any type of RP-generated pattern can be used. It offers good accuracy and finish from a long lasting steel tool, and many users have made more than a million parts from a Keltool mold. The main limitations are that the size of mold inserts that can be created are fairly small, on the order of a cube six inches on a side, and thin walled sections may not be possible to fabricate. Some customers have used multiple molds joined together to get around the size limitation.

The process starts with an RP pattern from which a rubber mold is created. The rubber mold is then used to cast a steel powder and polymer binder mixture into the mold geometry which after hardening is in a green state. The green mold is fired and copper infiltrated resulting in a tool with about 70% steel and 30% copper content. Ejector pins, cooling lines and other accessories may be added in final machining and polishing steps. In some cases little or no finishing is required.

The inserts are strong enough to withstand typical injection molding temperature and pressure conditions, and it's possible to use filled plastics and perform die casting with them. The method is advantageous for small, complex molds that would require much time to make with CNC or EDM techniques.

3D has been treating *3D KeltoolTM* with benign neglect, concentrating its efforts on other technologies it has since acquired such as selective laser sintering.



Direct Rapid Tooling – Direct AIM tooling Stereo lithography-based Tooling

Several efforts have been made over the years to directly fabricate molds using epoxy-based stereo lithography materials. *Direct AIM TM* from 3D Systems has probably received the most attention, but has not been widely adopted because of its limitations. A special stereo lithography build style is used. (AIM stands for ACES Injection Mold and ACES is an acronym for Accurate Clear Epoxy Solid.) The method has been said to be useful to manufacture short run or prototype quantities up to approximately 50 pieces of small, less-complex thermoplastic parts. Depending on the part geometry, it may be necessary to back the mold with epoxy to provide strength. The molds typically require secondary finishing operations before use to remove stair-stepping and improve finish.

Molds made using stereo lithography are used in injection molding machinery, but here again the parts fabricated won't be identical to those created in a high volume mold. Cycle time must be considerably longer due to the poorer thermal conductivity of the material compared to metal, and lower pressures must be used to accommodate its lower strength. The slower cooling cycle required may actually provide advantages for specific part geometries and materials. Glass-filled plastics aren't recommended and its very important to study the limitations of the process as it applies to the specific application.

The delicate nature of a mold fabricated using stereo lithography can lead to failure on the very first shot according to some users, so appreciable caution is necessary. The introduction of higher strength and temperature-resistant composite photopolymers may breathe new life into this method.

Direct Rapid tooling – Copper Polyamide Rapid tooling

The Copper Polyamide tooling process from DTM (Austin, Texas) involves the selective laser sintering of a copper and polyamide powder matrix to form a tool. All of the sintering is between the polyamide powder particles.

The process boasts an increase in tool toughness and heat transfer over some of the other soft tooling methods. These characteristics are provided by the copper and can give the user the benefits of running a tool with pressure and temperature settings that are closer to production settings. The primary disadvantage is the low material strength.

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Direct Rapid tooling – Quick Cast process tooling

Indirect or Secondary Processes that Utilize RP-generated Patterns

RP-generated patterns can be obtained from fused deposition modeling (FDM) in wax, selective laser sintering (SLS) in polystyrene or other plastics, and inkjet technology in wax-like plastics.

These materials may be melted or burned out of the investment very cleanly. The patterns from these processes tend to be small to medium in size, and especially for inkjets, offer the highest resolution and detail.

Stereo lithography is also used to produce patterns for investment casting, but the photopolymer materials used in that process are more difficult to burn out than the materials used in others mentioned above, and also have a tendency to expand and crack the mold. To get around these problems, 3D Systems has produced a special build style for this application, with the trade name *QuickCastTM*. The RP-generated pattern is built in hollow, thin sections which tend to crumple during burn out rather than expand and also results in a smaller mass of pattern material to remove.

The process has been developed over a number of years in partnership with large foundry companies and customers.

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Direct Rapid Tooling – Direct Metal Laser Sintering (DMLS)

Laser Sintering from EOS GmbH and 3D Systems Soft Tooling Using Metals

The EOS GmbH *Direct Metal Laser Sintering TM* (DMLS) process can use a bronze alloy which offers a step up in soft tooling over plastic-based stereo lithography methods. Harder, more thermally conductive materials mean that it's possible to run an injection molding machine closer to final mold conditions. There will still be differences between parts made with bronze alloy and tool steel molds, but not as great as that with epoxy tools. The resultant mold core and cavity inserts are porous, and it may be necessary to infiltrate them with epoxy or low melting temperature metal prior to use.

As many as several thousand relatively simple parts have been produced from such DMLS molds. In addition to limited life, soft metal tools generally can't reproduce fine detail and must be finished before use.

3D Systems formerly offered a similar process using a copper polyamide material.

Hard Tooling and Metal Parts

3D Systems' selective laser sintering process for metals uses polymer-coated steel powders. The resultant green part is burned out, sintered and infiltrated with bronze in secondary furnace operations to produce a fully-dense mold with about 70% steel content. These burn-out and infiltration procedures typically take about a day. The SLS metal part fabrication process has been greatly improved over the years to improve accuracy and resolution, and reduce stairstepping. The latter are critical improvements for hard tools because it doesn't make much sense to be able to quickly produce a hard steel tool if lengthy hand finishing and final machining eat up that advantage compared to CNC.

EOS's competing DMLS process for bronze alloys and steel powders doesn't require secondary sintering and burnout cycles in a furnace because the parts produced are already at 95% density.

This is a result of a difference in the basic philosophy of how each company has designed its machinery. EOS has chosen to build separately optimized systems for plastics and metals, while 3D has chosen to build more flexible systems which can utilize both classes of materials. The EOS metal part producing machines use more powerful lasers which result in increased density after sintering. Indeed, in some scanning areas the metal is completely fused.

EOS has also paid a great deal of attention to limiting the amount of secondary finishing required and they claim that customers often use their molds for production after simply a quick shot peening. Both steel and alloy metal powders are available that produce 20 micron (0.0008 inches) layers.

These steel-based processes offer the greatest benefit for small, complex geometry parts that would be difficult to machine. Conformal cooling channels can be incorporated into the molds which should last for hundreds of thousands of shots of almost any plastic. Some thought has to be given to conformal cooling channel geometry, however, to make certain that unconsolidated build powder can be removed after fabrication.

EOS introduced a cobalt-chrome alloy in August, 2006, which was initially developed for dental applications. Better operation of parts at elevated temperatures, and with improved strength and corrosion resistance are said to result. The company indicates it is also working on titanium, and 3D Systems has supported much research in aluminum materials at Queensland University (Australia).

Direct Rapid Tooling – Direct Metal Laser Sintering (DMLS) : PROMETAL RAPID TOOLING MACHINE

Pro Metal TM from ExOne Company

Pro Metal TM technology is an application of MIT's Three Dimensional Printing TM process to the fabrication of injection molds. Steel powder layers are bonded by photopolymer selectively applied by a wide area inkjet head. The photopolymer is cured layer wise by a UV lamp mounted on the head assembly. The green part thus formed is then sintered to form a porous steel matrix which is subsequently infiltrated with bronze. Considerable surface finishing is said to be required. Molds can be used to make hundreds of thousands of parts out of nearly any plastic.

ExOne Company was formed by spinning out several disparate technologies from Extrude Hone in 2005 when that company was purchased by Kennametal. ExOne Company was formed by spinning out several disparate technologies from Extrude Hone in 2005 when that company was purchased by Kennametal.

Direct Rapid Tooling – Sand casting tooling

Direct Fabrication of Sand Casting Patterns

It's possible to skip the step of building a pattern for a sand casting mold altogether. This may be advantageous in the early stages of a project before final dimensions and other parameters may have been determined, or if very few castings are required, making the cost of producing a pattern prohibitive.

Selective laser sintering (SLS) systems are available that fuse polymer coated sand layer by layer to form sand casting molds. EOS GmbH has dubbed this method *DirectCroningTM*. One limitation is the size of molds that can be produced.

A solution for much larger parts is offered by ProMetal RCT GmbH (Rapid Casting Technology) of Germany. Their machine use a wide area inkjet to bond layers of sand into sand casting and core patterns, and has a build volume of 59 x 29 x 29 inches. The method is reminiscent of the 3 Dimensional Printing process developed by MIT. A build chamber full of sand weighs several tons.

Direct Rapid Tooling – Laminate tooling

Laminated Tooling and Part Fabrication

Another technique which has received quite a bit of development over the years is laminated tooling. Several laminated tooling methods have been available for years on a limited basis, or have been used strictly in-house as proprietary technologies, particularly in Europe.

Laminated tooling is essentially the adaptation of the laminated object manufacturing (LOM) process to the problem. Work dates back to the earliest days of the RP field circa 1986 when LOM pioneer firm Helices, then known as Hydrometrics, was being in part supported by the John Deere Co.

In general, profiles are cut using various means from metal strips or sheets which are then either bonded layer wise or tightly held in a frame to form injection molding, stamping or other tools. Work has also been carried out at universities in the UK, the Fraunhofer Institutes in Germany (Metal Laminated Tooling process - MELATO), and in the US at MIT and elsewhere on similar technologies.

One advantage is that the method can provide somewhat larger tools than other additive technologies.

Laminated Tooling

Laminated tooling is an alternative to building cavities directly on an RP machine. Using the similar principles to the Laminated Object Manufacturing (LOM) process, layers of sheet metal are cut to replicate slices through a CAD model. Laser cutting or water jet technologies generally produce the profiles.

To produce a mold tool, the CAD model must take the form of the required cavity. By cutting all of the slices of the cavity in sheet metal, a stack of laminates can be made to replicate the original CAD model. Using either clamping or diffusion bonding, it is possible to create a pseudo- solid cavity in hardened tool steel without the need for complex post process cutter path planning. Due to the use of relatively thick laminates - typically 0.040 inch (1 mm) - the surface finish of the tools is generally poor; therefore, some form of finish machining is generally required.

Laminated tools have been used successfully for a variety of techniques including press tools, blow molding, injection molding and thermal forming. Research also is being performed into the use of laminate tools in pressure die- casting. Tool life is a function of the initial sheet material, which can be hardened after cutting and lamination. However, part complexity is bounded by layer thickness.

One significant advantage of laminated tooling is the ability to change the design of parts quickly by the replacement of laminates (if un- bonded). Conformal cooling channels also are easily incorporated within the tool design and laminated tooling is good for large tools as well. The need for finish machining to remove the stair steps is the main disadvantage of this process.

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