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Rapid Tooling: A Review

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Abstract-- **Rapid Tooling defines a process arising from the integration of Rapid Prototyping techniques with conventional tooling practices. The objective of Rapid Tooling process is to generate a mould quickly or parts of a functional model from CAD data in less time and at lower costs compared to traditional machining methods. This paper reviews the suitability of various RP technologies for making model as a pattern for casting and moulds for injection moulding. The direct and indirect techniques of generating casting patterns and tool making have been explored along with various approaches. Among different techniques this paper is focused mainly on Rapid Tooling via FDM and SLA. The FDM (fusion deposition modelling) is a rapid prototyping technique which is mainly used to make patterns for investment casting with the help of varieties of materials. There are different non-wax materials available in the market that can be used for pattern making and can be easily burned during autoclaving/firing. Various accessible FDM materials and their characteristics were presented. The accuracy of the pattern depends on a number of process parameters for FDM.**

Keywords —ABS, FDM, Enhanced Silicone Moulding, Rapid Prototyping, Rapid Tooling, SLA.

I. INTRODUCTION

As additive manufacturing technologies have evolved over the past decade, the applications of rapid tooling also have seen a great progress. From concept to commercial practice, for testing and modifications it is necessary to build a prototype. Earlier for functional part evaluation, the parts must be in the final design stage. But now to test alternative designs, designers use prototype parts. Parts of prototypes may vary from conceptual to functional. The parts must be dimensionally accurate and close to the final component used in production. When improvement of the production process is required, it is particularly useful to closely replicate the production process itself. Early RT techniques were based on different polymer materials, but the use of metals in rapid tooling techniques has increased dramatically over the last few years. This is mainly due to the increase of newly produced rapid prototyping systems classified on the basis of powder metal materials such as titanium, stainless steel, aluminum, and cobalt-chrome in recent years. On the other hand, rapid tooling techniques have some limitations in terms of surface finish, mold material, mold life, chemical properties and dimensional accuracy. Rapid tooling can be divided as soft tooling and hard tooling. The soft tooling is widely used for injection molding of plastic parts and can withstand between 100 to 1000 shots. Usually, soft tools can sustain the production of a single cast or small batch before failure, so they are called as soft tools. Hard tools, have been a major focus for research in recent years, and a lot of research is still being done in this area. DMLS, Rapid Tool, 3D Keltool, Eco tool, and Pro Metal are some examples of hard tooling. AM tooling's short lead time can reduce time to market and cost significantly. Designers will need a prototype that will be used in final production by the process produced in the end use material [1]. Apart from soft tooling and hard tooling RT is classified as indirect RT and direct RT which we can see in next two sections.

II. INDIRECT TOOLING

The tooling method in which models created from RP process are used as master patterns to produce the moulds is called as an Indirect Tooling. However, the purpose of these tooling method is not to replace or substitute manufacturing tools, but to provide a limited number of components. This method of indirect tooling includes:

A. Vacuum Casting

In this method the pattern is suspended in a vat of liquid silicone or RTV rubber. The mold that is formed around the pattern as rubber hardens. Then mold is sliced in half and pattern is removed so that model cavity will be made. The final Tools produced by this method have very good accuracy. Urethane and Epoxy are the materials which can be poured into a cavity to produce a prototype part [2].

B. Sand Casting

In this method mold is built by compacting a sand mixture around the pattern to form a model cavity. After this molten casting liquid is poured into the cavity. Sand casting is used for metal parts in maximum cases. It is used when very limited number

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of parts are needed in production [2].

C. Investment Casting

It involves coating of ceramic shell around the wax model. The model during the autoclave process must not expand because it hardens the shell during formation of mold. After this wax model is melted which will leave a cavity as a tool. Then molten metal can be poured into a cavity to form a part [2].

D. Injection Moulding

The mold is formed by encapsulating the model with composite or aluminum filled epoxy material to form the tooling. The resulting tooling is used in the injection molding process [2].

III. Direct Tooling

With the help of these tooling method a core, cavity can be created directly using rapid prototyping process. Due to this there will be reduction in certain steps which will reduce total development cost and time by 50 to 70%. For this method, some available techniques include:

A. Rapid Tool

With the help of SLS method metal mold is created and this mold is used to produce about 50000 parts by injection moulding process [2].

B. Laser Engineered Net Shaping

For this process CAD data of final metal tool is required. Then laser beam is used to melt the area or region of tool where material is to be added. The tool is created layer by layer by applying the desired material to the melted region. This method is applicable and is ideal for tools with a uniform and simple cross-section [2].

C. Sand Molding

A sand moulds are created directly from CAD data.

IV. Comparision Of RT Techniques

The rapid tooling technologies discussed in previous sections are very different from each other. A difference between these two techniques is important as they give the manufacturer a variety and range of processes to choose from. In this section, a comparison of such techniques is made using parameters such as life of tool, cost required for tool development and time required for tool development.

Life of Tool (no. of parts)		
10 to200	***201 to 2000***	***> 2000***
Castable Resin Mold Plaster Mould Castable Ceramic Mold Silicon Rubber Mold	Arc metal spray Direct AIM SL Composite	Rapid Tool 3D Keltool

Table 1. Life of tool

From Table 1, it can be seen that about 10 to 200 parts can be produced by indirect soft tools before failure occurs. This rapid tooling technology has a short and limited tool life. RT technologies in which RP parts is coated with sprayed metal in the case of arc spray metal tooling and comparatively harder resins used in SLA process for direct soft tooling thus have a tool life of 201-2000 bits. Before any visible wear of the tool is observed, rapid tooling technologies which uses hard tooling are capable of producing far more components, and some of these technologies account for as many as one million parts. SLS is also put under this category for sand casting moulds where each of laser sintered mould is used once, and due to tool wear, there is no loss of detail [3].

Tool Cost (in dollars)		
500 to 2000	***2001 to 10000***	***> 10000***
Silicon rubber mold Castable Resin Mold Plaster Mould SLS of sand-casting mold Castable Ceramic Mold	Arc metal spray Direct AIM SL Composite	Rapid Tool 3D Keltool

Table 2. Tool cost

The tool cost (Table 2) for indirect soft is shown with the exception of arc spray metal tooling, is the lowest ($500-$2000). But the cost of the tool not only takes into account the cost of the RP master, but also the cost of the manufacturing of the tool and the backing material for the tool. In arc metal spraying tooling additional cost is needed for fabrication of tool steel bloster which is required to resist high pressure during injection moulding process. Thus, total cost for this arc metal spraying tool is around $5000 and that is a reason it is placed in the next category, along with the direct soft tools. The tooling expense for direct soft tooling is more because machining time required for RP equipment is more. For certain hard tooling technology, the cost of tool manufacturing is higher because of the cost of the hard tool as well as the long tool making time on the RP equipment [3].

Time required for Tool Development		
< 1 week	***1 to 2 weeks***	***>2 weeks***
SL Composite Direct AIM	Arc spray metal Castable Resin Mold Plaster Mold Castable Ceramic Mold	RapidTool 3D Keltool

Table 3. Tool development time

The time required for tool development of direct soft tools is much shorter because manual work required to produce these tools is very less. And if these processes require a manual work, it is usually for finishing operations like polishing, washing and sanding (see Table 3). Next, time required for tool development in

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between 1 to 2 weeks is required for indirect soft tooling to produce the tool from the RP master pattern and for additional manual operations. And for RT technologies like Rapid Tool and 3D Keltool that produce hard tools, the time required is longer, as additional process time is required for post curing operations [3].

V. LITERATURE SURVEY

Author	*Objective*	*Rapid Tooling Process (Materials used)*	*Rapid Prototype Process (Materials used)*	*Conclusion*
P.Dunne	To create a mould using two processes (Enhanced Silicone and Foundry Casting) and this mould is used to produce parts by injection moulding. The master pattern is made by rapid prototype process [4].	Enhanced-Silicone Moulding (Silicone Rubber) and Foundry Casting (phenolic resin coated ziron sand)	SLA (Photopolymer)	Surface finish is more critical to ES molding and heat resistance mainly effect on foundry sand process. Whereas porosity and dimensional accuracy effects both.
K.Subburaj	Development of auricular prosthesis for 19-year-old male using rapid prototyping technology. The proper position and dimensions of the prosthesis were done by stacking the CT scan images of the contra-lateral normal ear in reverse order, and joining with the help of medical modeling software [5].	Enhanced-Silicone Moulding (Medical Graded Silicone Rubber)	FDM (ABS P-400 R) and 3D Invision (Acrylic Paste)	Both FDM and 3D InVision made RP models were found to offer strength and good accuracy in this investigation, but FDM was found to be more feasible. The combination of RP and traditional 3- piece mould for final silicone prosthesis lowers production costs relative to previous work.
J.C.Ferreira	Integration of rapid tooling and reverse engineering in foundry technology.3D digitizers is used to create a model and this model is used as a pattern for sand casting [6].	Sand Casting	SLS (Nylon Powder), SLA (Photocurable resin) LOM (Paper material)	3D-digitising and RE improve the metrological precision of foundry processing technology and marketing competitiveness in product production and RT. In the foundry industry, the combination of RE with RT technologies reduces lead time and related costs.
S.H.Masood	To develop a new material for FDM process. The feedstock filaments of this composite have been produced and used successfully in the unmodified FDM system for direct rapid tooling of injection moulding inserts. High quality plastic parts have been injection moulded using the inserts [7].	Injection Molding	FDM (ABS and LDPE)	The use of this new composite material in rapid tooling using the FDM method has demonstrated that it is possible to effectively manufacture high quality parts and injection molding tool inserts. The material is particularly suitable for the implementation of direct rapid tooling. No binder burnout or infiltration is needed in this work.
C.W.Lee	The Reference model is designed to evaluate the FDM method for generating sacrificial investment casting patterns. In comparison an indirect approach to the development of wax patterns through silicone rubber molding is examined. [8].	Investment Casting (wax for conventional and ABS for RT)	FDM (ABS)	Lead time and cost is compared between the two-investment casting pattern production methods. By comparing the lead time and cost needed for the creation of a wax pattern using silicone rubber molding to the use of a metal mold in the traditional IC process, considerable time (89 per cent) and cost savings (50 per cent) can be achieved using the indirect RP system.
M.F.Omar	To determine the quality characteristics of the different RP patterns that has been generated by different RP processes including (FDM), (MJM) and (3DP). Evaluation of the patterns was conducted on surface roughness, pattern shrinkage, and dimensional accuracy [9].	Investment Casting	FDM (ABS), MJM (Acrylate) and 3DP (Ceramic Powder)	The dimensional review concluded that FDM and MJM processes generate more accurate patterns with a low dimensional deviation compared to those generated by the 3DP process. The internal design style of the RP patterns was found to have negligible impact on the final surface roughness of all RP parts.
S. Rahamati	Injection mould tools were built by SLA method for short term production. SLA tools have been tested to analyze the maximum no. of successful and effective injected parts and quality of performance. SLA tools made of epoxy were able to resist the temperature and injection pressure. Around 500 parts were produced by Injection tool [10].	Injection Moulding	SLA (Epoxy)	500 parts were created by SLA tool before failure of tool is observed. Failure mechanisms of SLA SLA tool have been discussed and different conditioned have been shown. The very low thermal conductivity of the SL instrument and the short injection time are crucial to the effectiveness of this technique.

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Y.Ding	Three cases are discussed: Creating mould for Arc metal spraying process, Production of electrodes for EDM process by electroforming process and abrading process [11].	RTV Moulding (Bi Sn alloy)	SLA	Rapid tooling gives a fast and effective method to produce mould, and also have great reduction in time and cost compared to conventional methods. This system provides a better and valuable method for companies to accelerate the development.

VI. Limitations

This section explains some of the drawbacks that can be found in the present RT methods. Although not fully detailed, it presents its major limitations from the RT perspective.

A. Density

One of the most important properties needed for tools, and molds in particular, is a nearly full relative density. The dimensional accuracy of the mold will also affect porosity in the case of injection molding, since the material can densify more under injection and retain pressure after a few hundred cycles. SLS and 3DP do not contain components of complete density. In both cases, before the treatment, the powder cannot be compacted. In the case of SLS, exposure techniques play a key role in the consistency of the product. The construction time is very high if a high relative density is needed, Since the beam paths must be very close to each other and the speed of the scan must be low, the reduction in time can then be less noticeable and the density is still lower than about 80%. Since density is a major parameter that affects the tool's strength, durability and surface quality, it is very important that the DRT methods can produce almost entirely dense parts with as much as they can and with variety of materials [12].

B. Dimensional Accuracy

With a given RT method, it is necessary to know what dimensional accuracy can be achieved. Numerous parameters influence accuracy: precision handling of CAD images, material properties and processing parameters. Precision handling of CAD images sufficiently reliable, but material properties and processing parameters are subject to significant changes. In the areas of beam efficiency, control of shrinkage, material behavior and powder granulometry. In area, process simulation can bring valuable improvement [12].

C. Surface Roughness

Surface roughness of mould is one of the critical properties for the plastic injection molding process. It has a huge effect on quality of final produced part and ejection of part from mould. Granulometry, along with parameter optimization, is an integral element influencing roughness. At the moment, infiltration is an appropriate way to enhance [12].

D. Chemical Properties

Mold produced for injection molding process are frequently exposed to chemicals like lubricants, additives and different gases (chlorine or ammonia) during process. During this condition a mold material should be highly resistant to chemical degradation and corrosion. High thermal conductivity is another significant property of molds, as cycle times can be much shorter and fewer cooling channels are required [12].

E. Mechanical Properties

The strength of a tool basically depends on the properties of the material, porosity, the existence of defects (voids, oxide layers, cracks) and internal stresses present in the component. The moulds must have a good mechanical strength in order to withstand or resist injection pressures. And surface roughness must be good to be ensure that the hardened material's abrasive effect is resistant to wear [12].

VII. Conclusion

- Indirect and direct rapid tooling techniques, along with the most promising methods, are reviewed in this paper, and their essential properties and limitations are described.
- It is important to develop and improve all methods, since there is no one method that can be assumed to be perfect.
- The main issue of concern in modern metal-based processes is materials, especially powders. Required research and advancement are described for rapid tooling technique.
- Direct RT methods allowed the manufacturing tools to achieve metal density of 70-95 percent, which is suitable for applications such as wax tooling, metal casting and plastic injection molding with low melting point.
- There is a fact that property like density is affecting surface quality, tool strength and life. Therefore, main purpose of rapid tooling method is to substitute manufacturing equipment, although this is only feasible by improving the strength of RT tools using additive manufacturing processes based on metal.
- Significant development is required in different fields of rapid tooling and rapid prototyping like: CAD/CAM software, powders, materials, powder delivery systems, laser optics, and part build-up strategy.
- A significant effort is needed to model physical

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processes such that improved production methods and process scans can be done along with experiments. DRT includes a powerful multidisciplinary analysis that ultimately involves various technical domains.

VIII. Future Scope

The aim of rapid tooling at present is not necessarily to create the final parts, but to build the tools for the preparation of final parts. It is still difficult to meet the full specifications of direct rapid tooling, particularly for plastic injection molding tools, although it is recognized as a first area of application. It would fully qualify as a low volume or prototype tooling process when the DRT tooling directly simulates the properties of the conventional molded parts. The various criteria, including the following, must also be fulfilled in order to achieve these objectives [1]:

- In order to resist injection pressures, moulds must have strong mechanical strength.
- It is important to carry out further studies to consider the deviations in the final physical features of the injection molded parts using DRT tools vs traditional hardened steel tools.
- Improving the dimensional accuracy of the mold.
- Porosity can lead to failure of the tool due to lower elastic limit, mechanical strength, toughness and Young's modulus; & the surface quality is another property which may also be affected.
- The surface quality of the DRT tool must be close to perfect for easy ejection of the part and to minimize finishing operations.
- Improved or better surface roughness is important in plastic injection molding, since it can cause complications during part ejection and lead to a longer cycle time.
- Direct rapid tools must be wear resistant to have a good tool life.

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