# Rapid Tooling Technologies Based on Additive Manufacturing: A Comprehensive Review

**Ganesh Borikar, Varun Velankar, Sanjana Joshi, Parth Dandawate, and Sachin Deshmukh**

**Abstract** This study aims to give an overview of additive manufacturing-based rapid tooling technologies. Rapid tooling is a pre-production segment where AM technologies truly shine, as the tools to be manufactured are less in quantity, and each component should be custom-made according to the process requirements. Therefore, a case study to compare the two manufacturing processes for the production of components based on cost and time constraints is showcased. According to the case study analysis, we can infer that FDM technology offers better cost when it is to be produced in small quantities and when the requirement for customization is very high. In injection molding, the flexibility is significantly compromised, but it yields better results when the component is to be produced in large quantity. In conclusion, it has been shown that the FDM process is advantageous for small businesses or luxury automakers that produce small-scale components.

**Keywords** Additive Manufacturing (AM) · Rapid tooling · Time-cost analysis · Fused Deposition Modeling (FDM) · Injection Molding (IM)

## 1 Introduction

A modern manufacturing technique called additive manufacturing has completely changed how we prototype things for the manufacturing sector. The most widely used additive manufacturing techniques include wire arc additive manufacturing, fused deposition modeling, stereolithography equipment, selective laser melting, selective laser sintering, and binder jetting. These manufacturing technologies for tools are outlined together with the materials employed. Also, utilized as an example

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is a case study on the cost-time analysis of the "filter media" portion of the oil filter used in the automotive sector.

## 2 Literature Review

Tools are produced swiftly using techniques like FDM and SLA [1, 2]. Less lead time to market and the removal of several traditional production procedures, such as tooling, assembly, transportation, etc., will result from the development of additive manufacturing. It will make feasible to produce the same product in many ways. Supply chains will be more affordable, compact, and flexible [3]. We must consider two crucial requirements before using a 3D printed component in real-world applications: Any Von-Mises stress applied to a fixture component should be less than the component's yield strength, which was obtained by 3D printing the component. Moreover, the factor of safety should be at least 1.5.

These conditions can be determined or calculated by any computer-aided engineering (CAE) software. If the above two conditions are satisfied, then the material (used for additive manufacturing) can be used to manufacture that component [4]. But, there are various other factors, for example, evaluation methods to determine whether a jig or fixture has to be produced using additive manufacturing or conventional methods [5]. We can determine whether a hybrid welding jig system with AM functional elements and interfaces can provide technical and economic advantages for different types of welding jigs in the automotive sector [5–7]. Here are some examples of quick tooling processes: Selective laser sintering (SLS) is used to create location components for free-form part indexing [2].The manufacture of semi-auto insertion jig components such as baseplates, connections, E-bits, base plate supports, and LR jigs uses a AM [4]. Robotic goods that are lightweight and extremely precise have several applications [8]. While pieces were being positioned during welding, the disk support sub-assembly of the agricultural machine stubble cultivator was put together [9]. To prevent deformations in the scanned model, fix the component securely in place before scanning [10]. Developed measuring fixture, checking fixture, or climatic fixture to conduct tactile and visual measurements [11, 12]. Employed additively manufactured jigs and fixtures in automotive applications when lead times are greater and items are needed immediately [13].

## 3 Types of Rapid Tooling Processes

### *3.1 Fused Deposition Modeling (FDM)*

It is a solid material-based system that uses an extrusion nozzle and material in the form of filaments to print parts (Fig. 1) of every complexity and nature at a less cost

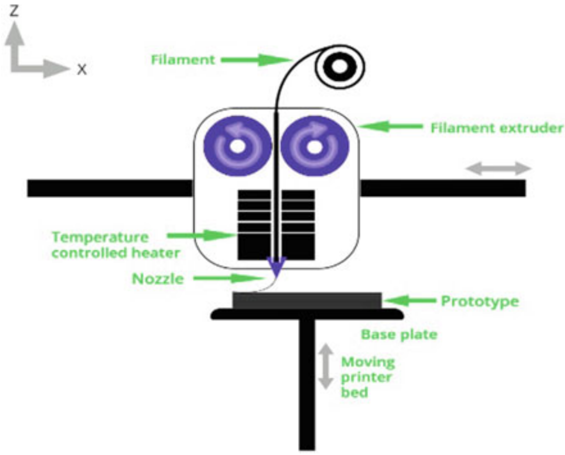


**Fig. 1** Fused deposition modeling (solid-based system)

and good accuracy. FDM is one of the most affordable and convenient processes for quick and time-bound applications like pattern making, prototyping, and fabrication of jigs and fixtures. This technology mainly uses various thermoplastic materials in the form of wire filament, which is then melted and extruded onto the build platform to create the model layer by layer.

Preferred materials used for the FDM process: *Polylactic Acid (PLA)*: It has low melting point, low thermal expansion, high strength, brittle, and high flexural strength. *Acrylonitrile butadiene styrene (ABS)*: low melting point, high strength, ductile, and high thermal stability. *Thermoplastic Polyurethane (TPU)*: low melting point, high elasticity, abrasion-resistant, brittle-ductile phenomenon, high chemical resistance. *Polyether ketone (PEEK)*: creep resistance, dimensional stability, high strength, crystalline nature. Tooling developed—a welding fixture used in the automobile industry using ABS as material [9].

## *3.2 Stereolithography Apparatus (SLA)*

In order to solidify the liquid resin monomer into polymers and create the required model, the liquid-based additive manufacturing (Liquid-based AM) technique, as seen in Fig. 2, requires a laser beam. SLA is a kind of vat photo-polymerization that relies on photochemical curing to function. The procedure, however slow, is appropriate for intricate, high-quality goods. A full setup of the SLA is shown in Fig. 3. Preferred materials used for the SLA process: *Standard resin*: It gives good surface finish, brittle, high accuracy. *Clear resin*: transparent, brittle, dynamic optical clarity, good surface finish. *Tough resin*: high stiffness, min. wall thickness of 1 mm, brittle. *Heat resistant resin*: good surface finish, high heat deflection temperature,

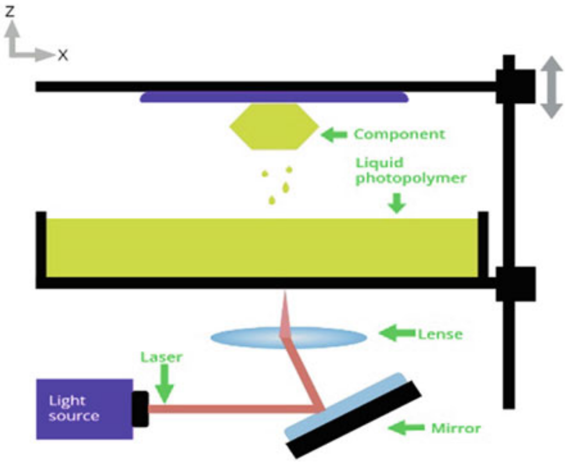


**Fig. 2** Stereolithography apparatus (liquid-based system)

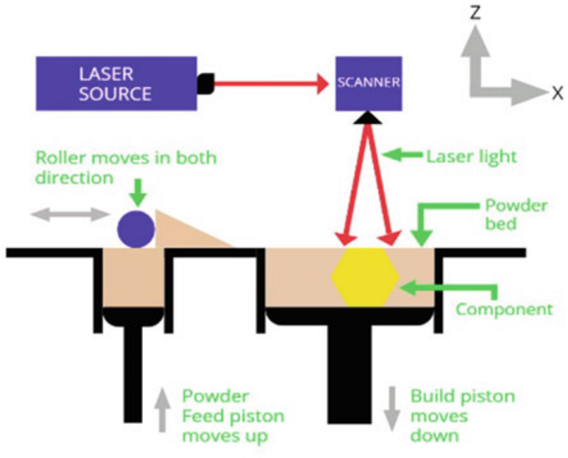


**Fig. 3** SLS/SLM (powder-based system)

brittle, minimum wall thickness of 1 mm. Tooling developed—skull models were developed using the SLA method [14].

### *3.3 Selective Laser Melting (SLM)*

Powder-based system that uses a laser as a heat source to selectively melt the metal powder to create the desired components (Fig. 3). SLM is an expensive and energy-intensive process as it requires a specialized laser for melting. The metal laser system consumes a greater magnitude of energy. This method can be employed to fabricate complex and specialized products with higher accuracy, functionality, and minimal post-processing. Preferred materials include Al, SS, Ti, and Cu alloys.

### 3.4 Selective Laser Sintering (SLS)

It is a technology that is similar to SLM in working (Fig. 3) and with main difference of SLM makes use of a full melting mechanism in which particles are completely melted and then fused, whereas SLS makes use of solid-phase sintering or liquid-phase sintering in which particles are sintered in solid-state completely.

Preferred materials (non-metal powders) used for the SLS process: *Polyamide 12 (PA 12)*: high strength, high chemical resistance, and surface roughness. *Aluminum-filled nylon (Alumide)*: high stiffness, lustrous. *Glass-filled nylon (PA-GF)*: high wear resistance, high-temperature resistance, high stiffness, anisotropic. *Carbon-fiber-filled nylon (PA-FR)*: high weight-to-strength ratio, high stiffness, anisotropic. Tooling developed lightweight robotic exoskeleton and lightweight metallic lattice structures developed using AlSiMg [8].

### 3.5 Binder Jetting (BJ)

Binder jetting is a powder-based system that uses a material binder that is selectively deposited onto the powder bed. Here, the binder acts as an adhesive to cure the component into the desired shape, layer by layer. The binder Jetting process has a unique feature in which two different materials can be combined to form a multi-color model. Binder jetting is very accurate. It is also the medium cost metal printing process. Figure 4 shows a detailed description of the binder jetting process. Different materials used for the BJ process: Binders: *Furan Binder*, *Silicate Binder*, *Phenolic Binder*, *Aqueous-Based Binder* Powders: *Metals*. Tooling developed—reactor packing material which is ceramic support is employed in the heterogeneous catalysis process [15].

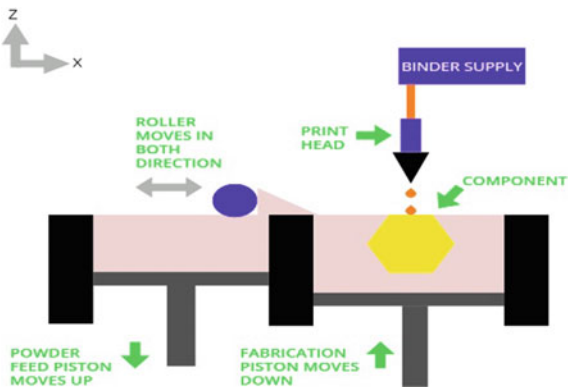


**Fig. 4** Binder jetting (powder-based system)

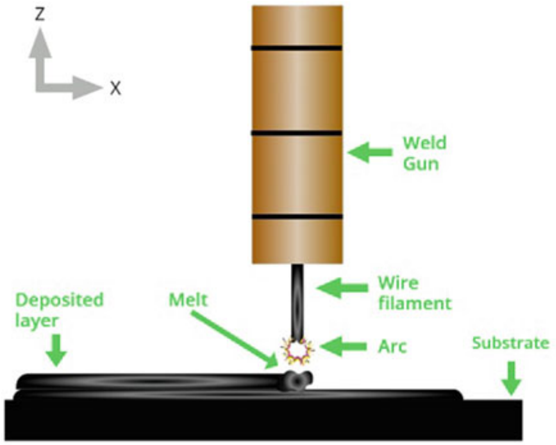


**Fig. 5** Wire and arc additive manufacturing (DED process)

## *3.6 Wire and Arc Additive Manufacturing (WAAM)*

WAAM, also now known as the direct energy deposition-based process, uses a metal wire electrode and melts and fuses it with another material to form a composite structure as shown in Fig. 5; the materials used are titanium, chromium, aluminum, Inconel, and Ti-6Al-4A. WAAM has a low cost and higher efficiency [16].

This technology has now evolved into a more accurate and efficient technology due to the use of 6 DOF robotic manipulators since welding is a contour application. Applications: Metal components in automotive, aerospace, and steel industries and also maintenance in welding companies. Common materials used for the WAAM Process: *Aluminum*, *Carbon steel, Copper, Stainless steel, Magnesium.* Tooling developed—Fabrication of complex metal parts in general.

## *3.7 Laminated Object Manufacturing (LOM)*

It is a solid-based technology that uses sheets as material. The materials are usually coated with an adhesive layer that is heated by a moving roller to apply pressure and heat the sheet and adhesive. In this way, each layer can be glued to the previous one to build up an object. This process is still under research and development, and very few firms across the world use it as a mainstream technology. Figure 6 shows the process of LOM technology. Preferred materials used for the LOM process: *Paper, Metal Sheets, Ceramics.* Tooling developed—patternmaking in sand casting, investment casting, and injection molding [17].

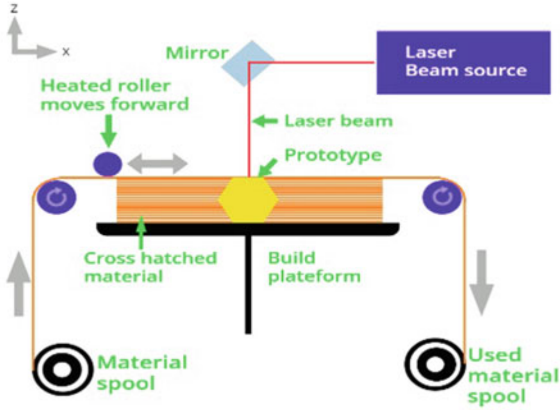


**Fig. 6** Laminated object manufacturing (powder-based system)

## 4 Tooling for Manufacturing

In any production process, it is essential. These include numerous machine tools, including as production, bridge, and prototyping equipment. It takes a lot of time and effort to create investment casting patterns, which might take several months in various metal sectors. Due to lengthier lead times and increased corporate competition, this causes issues in the supply chain. Therefore, using FDM technology, these designs may be 3D printed in a couple of hours. Jigs and fixtures, which are often created specifically for a component's size and manufacturing process, are the most crucial instruments in the manufacturing sector. FDM, SLM, SLS, and WAAM technologies can be used to 3D print these tools. They shorten lead times while improving precision and finishing. Phases were established throughout the entire approach. Phase 1 entails topic study and knowledge; Phase 2 entails analysis; and Phase 3 entails conclusions. Finding the time-cost analysis of FDM vs. injection molding technology was the methodology's ultimate aim. Tools like patterns, jigs and fixtures, molds, and frames may be produced more quickly and more cheaply by using additive manufacturing technologies [2].

## 5 Case Study: Time-Cost Analysis of Filter Media Used in the Automobile Industry

*Phase 1 Examine Current AM Technologies:* Extensive study was conducted about AM technologies to understand the topic more in-depth. Various types of research papers, projects, reviews, etc., were studied to get an idea about the same. From the above research materials, it was observed that for the production of industrial components, AM technologies have proven beneficial in terms of cost, with respect to time, cost, and accuracy. Components that are generally complex to manufacture using conventional technologies can be manufactured using different AM technologies depending on their application. The researchers brief more about the industrial component that will be additively manufactured, as well as the quality, cost, and time that can be reduced. Radhwan et al. [4] give a study of the additively manufactured welding fixture. The FDM process is used to manufacture the welding fixture. ABS was the substance employed in the procedure. A unique welding fixture was constructed for a particular acute angle weld using FDM technology, which decreased cost, lead time, and weight. 3D scanners were investigated by Kampker et al. [5]. A extremely complicated component can be exceedingly time-consuming to develop as a whole and may not be as precise as the original product. As a result, the component is completely scanned using 3D scanners before being printed, eliminating any possibility of error or subpar quality. In order to carry out a successful scanning process, a fixture was scanned and created to hold a component.

*Phase 2 Analysis*: An essential part of the car industry that is created using injection molding technology is filter media. If the component is to be produced in small batches (i.e., 250 components in this example), the FDM technique may easily beat the traditional injection molding process, according to the full time-cost analysis of these components. Conventional production techniques are ineffective in this situation since there isn't a vast volume of product to be produced. Due to their significant machinability challenges, these components can only be produced via injection molding technique.

Hereby, we have studied two technologies: FDM and injection molding. We have used FDM technology considering its demand in the industry and for conventional processes. We have considered injection molding since the conventional machining of these products is difficult. We have considered Ultimaker 2+ FDM printer to print this component and also calculate costs and lead time for the FDM technology using Ultimaker Cura software (Figs. 7 and 8). But, for the injection molding process, we have considered approximate costs provided by local business owner. (Refer to acknowledgment).

A time-cost analysis for the individual components is completed for the aforementioned two procedures after taking into account the quantity of components to


**Fig. 7** Design of filter media in Ultimaker Cura

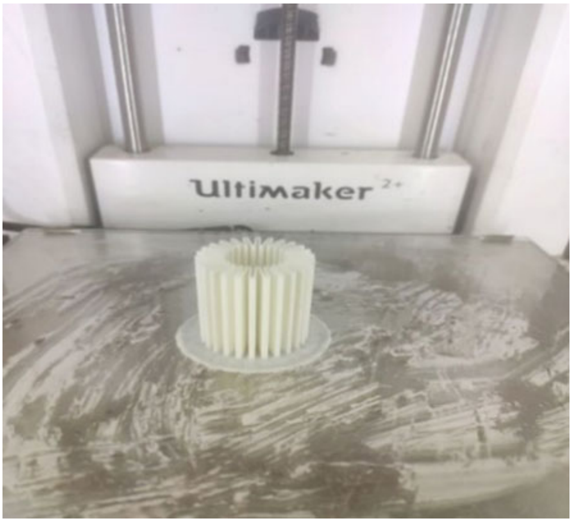


**Fig. 8** 3D printed filter media

be made. With the aid of the analysis, the cost of the first five components was determined rather than the next ten, raising the values. This cost was computed using factors including the cost of the spool (1 kg, 1.75 mm), the pattern ($266.6), and the speed (1 product/15 s). As the number of components changes, Table 1 compares the time and cost of the FDM and Injuction molding (IM) procedures. After 250 pieces, it is not advised to use the FDM technique since it wastes time and would add additional manufacturing days.

*Phase 3 Findings*: The two processes are compared for the manufacturing of filter media used in the automobile industry, which was manufactured in small batches.

The results of our analysis are as follows:

**Table 1** Time-Cost analysis (FDM versus IM)

| Quantity (the no. of components) | Cost (in US $) | | Time (in days) | |
|---|---|---|---|---|
| | Fused deposition modeling | Injection molding | Fused deposition modeling | Injection molding |
| 1 | 0.13 | 270 | 0.083 | 21 |
| 100 | 13 | 271 | 8.3 | 21 |
| 250 | 32.5 | 272.5 | 21 | 21 |
| 500 | 65 | 275 | 41.5 | 21 |
| 1000 | 130 | 280 | 83.33 | 21 |
| 2000 | 260 | 290 | 166.6 | 21 |
| 2250 | 292.5 | 292.5 | 186.75 | 21 |
| 2500 | 325 | 295 | 207.5 | 21 |
| 3000 | 390 | 300 | 249 | 21 |

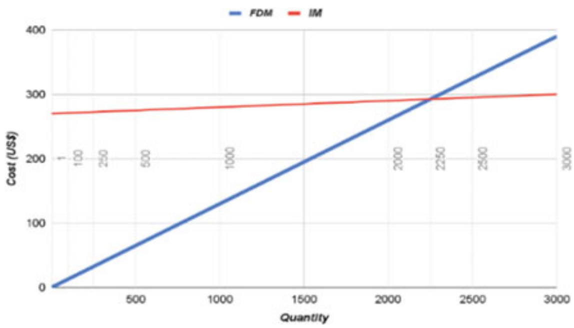


**Fig. 9** Cost analysis

*1. Inflection point for cost*: When components are manufactured individually by both the processes, the inflection point is obtained at the 2250th piece, where the cost of both the processes is almost equal. FDM is not a cost-efficient process if we want to manufacture more than 2250 pieces in this case. Therefore, injection molding should be employed to cater to the mass production requirements, considering 'cost' as a parameter (Fig. 9).

*2. Inflection point for time*: After manufacturing the 250th component, the inflection point is obtained where the time required to manufacture the same component using both processes is equal. To manufacture more than 250 components, FDM will take more time as compared to injection molding. Analysis shows that injection molding can produce up to 5500 components per day (without breakdowns); hence, the time taken will only be 21 days for quantities given in the above table. It will be detrimental for the company to use FDM processes for quantities greater than 250 even though the costs are lower as compared to injection molding as tooling is a time-critical process. Hence, we can safely conclude that for large quantities, injection molding has no alternatives, but for small quantities, FDM offers better prospects (Fig. 10). An *important point* to note in this analysis is that consumer automotive companies that produce cars in a huge quantity may have less possible use of AM processes.

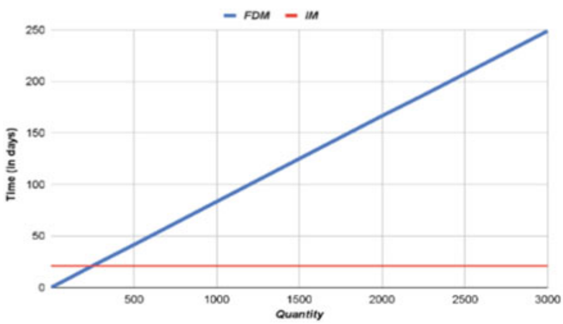


**Fig. 10** Time analysis

### *5.1 Sustainable Development Goals*

Additive manufacturing contributes significantly to the 8th, 9th, 12th goals of the UN SDG's which are to be fulfilled by the year 2030. Additive manufacturing as a technology also reduces material wastage, overall energy consumption contributing to the sustainability values that are needed to ameliorate the effects of climate change on society.

## 6 Future Scope

Additive manufacturing is a relatively new technology; it is still in its formative stages, and there is tremendous scope for research and development on the technology. Major industries benefiting from this technology are automotive, aerospace, and health care since there is a huge demand for new tooling processes in these industries that can reduce lead time and cost. These AM processes need to be more efficient in order to compete with traditional manufacturing processes, and they should be able to provide a better cost-benefit ratio. Although this technology is only limited to prototyping and limited customized segments of manufacturing, in the future, we can expect it to be as a consumer product which will be able to print things on demand.

## 7 Conclusions

The additive manufacturing (AM) processes that are currently used in the industry as *FDM, SLA, SLS, SLM, WAAM, BJ,* and *LOM* are reviewed from the perspective of rapid tooling technologies, key features and their associated applications. According to the current study, the FDM technique of rapid tooling is the best one for batch manufacturing/tooling but is ineffective when mass production is taken into consideration. In the present case study it shows, it is incredibly cost-effective and has shorter lead times than injection molding (IM) when producing filter media in quantities of fewer than 250 pieces. When the required output exceeds 2250, it becomes clear that FDM is no longer a time- and cost-efficient technique. For items with comparable sizes and quantities, this connection could be similar. The key finding is that AM tooling technologies/procedures work best for applications with characteristics: complexity, small batch needs (preferably less than 200), and are having specific requirements of product and tooling. These qualities may be ideal for luxury automakers, who typically modify their component designs and produce very few number of vehicles in a batch. These characteristics call for a high degree of flexibility, which AM technologies possess.

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