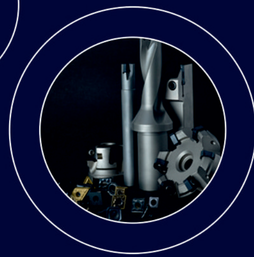
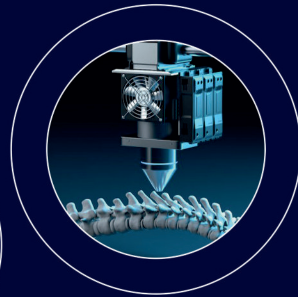
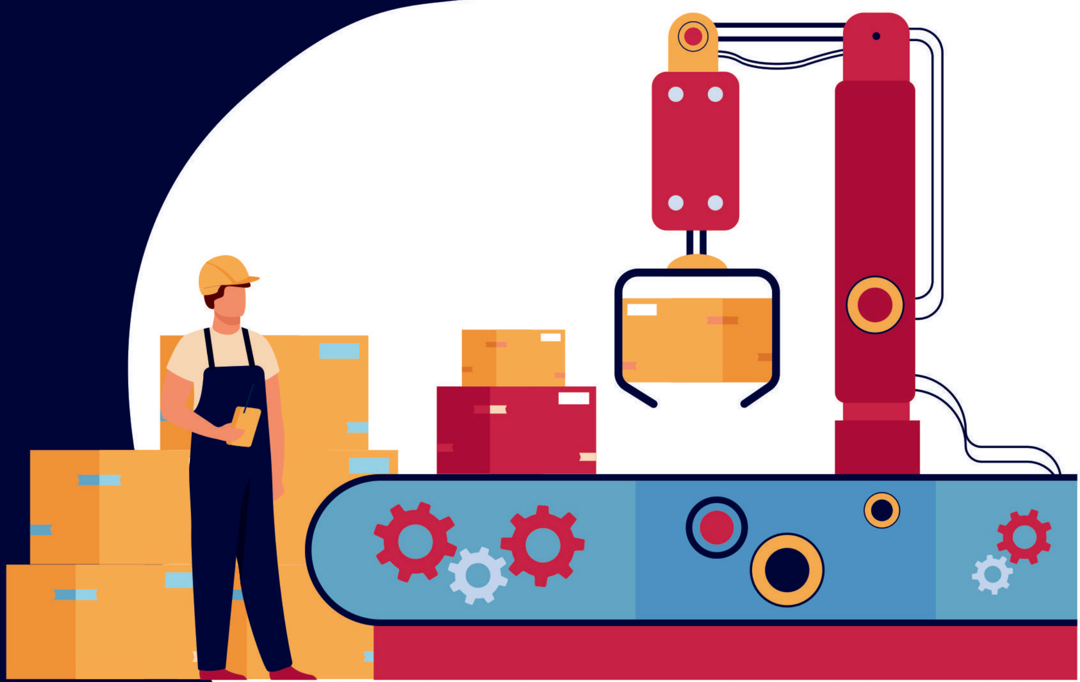




Additive Manufacturing

K. Ravi Kumar



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Additive Manufacturing

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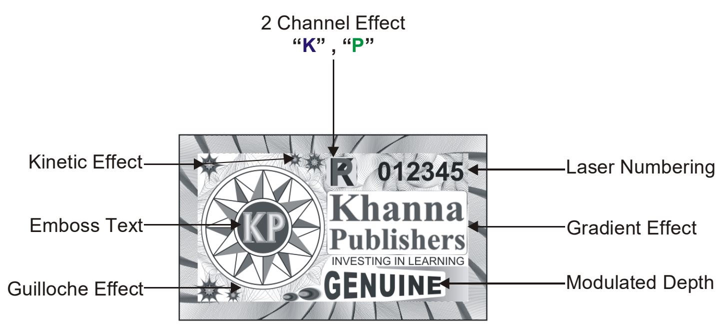

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Preface

Modern industry growth depends on cutting-edge, ground-breaking innovations in materials, manufacturing, and product design. The present state of production is characterised by complex product needs, shortened product life cycles, customised goods, and accelerated delivery time frames. New manufacturing techniques must therefore constantly be designed and developed. Any CAD software-created virtual shape design can be made into a tangible product via additive manufacturing. Additive manufacturing (AM) is a technique of merging materials layer by layer due to fusion, binding, or solidification. Additive manufacturing develops components layer-by-layer using the three-dimensional CAD model. Using a three-dimensional CAD model, additive manufacturing creates components layer by layer. Numerous industries, including aerospace, automotive, transportation, healthcare, and the military, have benefited from additive manufacturing technologies. The production of engineering and manufacturing processes will be based on additive manufacturing in the future.

The main objective of this book is to have a clear idea of the fundamental concepts of additive manufacturing and also the various factors that influence machining. This book focuses on the Working principles, Components, Machining characteristics/process parameters, applications, advantages and limitations of various additive manufacturing processes in detail. This book is designed for the benefit of engineers, designers, students and researchers of mechanical, production and industrial engineering.

K.Ravi Kumar

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Introduction

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CHAPTER

1.1. INTRODUCTION

Manufacturing has conventionally played a vital role in developing the economy of developed/developing nations. Industrial manufacturing includes industries like automobiles, aerospace, marine, machineries, electrical, metals, construction material, rubber, plastics, etc. The competition for manufactured products has intensified to a great extent in recent years. Products available in the market may not be adequate to manage the market needs and the industries need more innovative products acceptable by a majority of the customers. Hence effective timing in launching a product is vital in attracting customers with attractive features. ***Product development*** is the process of modifying an existing ***product*** or developing an entirely new ***product*** that satisfies the customer's needs. Product development undergoes various steps like conceptualization, design, developing and marketing the product to the target audience. Industries are in need of new tools and approaches to deal with product development. Continuous technological growth and development resulted in new manufacturing methods like rapid prototyping, additive manufacturing, etc. over the last few decades.

1.2. PROTOTYPE

Prototype is the first or preliminary version of a component or a machine from which other forms are developed. It may the simplest working model, representational model, scale model, or simulation of a product which guides to create the final product. Prototype is a model fabricated to test the particular concept or process before going for real-time manufacturing. It is used by experts and users to evaluate and analyze a new design to enhance precision of the product. Prototype can also be defined as an actual representation of a part or all parts of a machine that requires interpretation. Designers, managers, developers and customers can use the prototype to predict the performance and the same can be reflected on the final product. Prototypes broadly fall into three categories namely the functional prototype, display prototype and small model. The functional prototype focuses on the functional aspect of the product only, the display prototype concentrates more on the aesthetics rather than the function and the small model concentrates both the function as well as aesthetics and is the scale-down model of the final product. The material, fabricating process and verification procedure of the prototype necessary need not to be similar. Prototype contains three general aspects namely (1) Effective execution of prototype to a final product (2) formation from a virtual prototype to a physical model/prototype, (3) degree of execution from a very rough representation to a final product. Traditional prototyping involves processes such as sketching, manual drawing, cardboard/wood modeling, foam modeling, clay modeling, machining, vacuum casting, thermoforming, investment casting, sand casting, centrifugal casting, etc.

1.3. PROTOTYPING

Prototyping is a systematic approach for developing, testing and manufacturing a prototype to meet the required quality. The prototype is designed and delivered to the customers, feedback is then received from the customers, modifications are carried as per the feedback and the final model is developed. Though prototypes find their applications in all product industries, it is essential to produce the product at a faster rate, low cost and high level of accuracy.

1.4. PHASES OF THE PROTOTYPING MODEL

Requirements Analysis. The requirements of the product/part is defined in detail. Customers are interviewed based on some statistical procedure to identify their expectations towards a particular product.

Quick Design. A preliminary simple design outline of the product is created. It does not carry the complete design rather it gives a brief idea of the product to the customer. This design helps in developing the prototype quickly.

Building a Prototype. A prototype is developed based on the information available in the quick design. It represents a small working model of the required product. The prototype at this stage is usually a scaled-down model representing the approximate characteristics of the final product.

Initial User Evaluation. The developed prototype is presented to the customer for initial evaluation. This helps to identify the strength and weakness of the working model based on customer feedback. Suggestions are collected from the customer for product improvisation.

Refining Prototype. Based on the information available from the customers, the product is refined until all the requirements specified by the customer are met. A final product is then developed after incorporating all the possible suggestions given by the customer. The refining stage involves a number of iterations before concluding the final product as shown in Fig.1.1

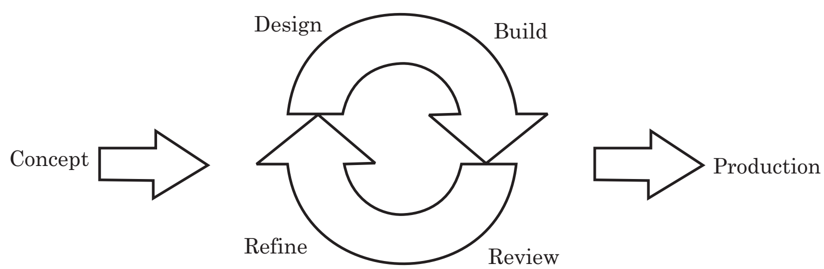

Fig. 1.1. Iterations in the refining process.

Product Implementation and Maintenance. The final product is thoroughly evaluated and tested for performance using standard protocols. Routine maintenance is carried out periodically to minimize downtime and prevent large-scale failures.

1.5. PROTOTYPE MODELS

Prototype models can be developed based on the product's requirements using the appropriate method. The commonly used prototype models are as below:

Rapid throwaway Prototyping. This technique involves developing a prototype rapidly based on the preliminary requirements and then submitted to the customers for review. It is then revised based on the customer's feedback and updated and the final product is developed based on the feedback. Customer feedback plays a vital role in preventing unnecessary design faults thereby improving the quality of the final product. In a throwaway prototype, the developed prototype is completely discarded after evaluation and need not necessarily be part of the final product and is commonly known as close-ended prototyping. This method helps in getting feedback from the customers at a faster rate.

Evolutionary Prototyping. In this approach, a prototype is developed and feedback is collected from the customer. The prototype is incrementally refined until the customer is satisfied. In an evolutionary prototype rather than developing a new product from the scratch an existing prototype is reworked and hence this technique saves time and effort. This model is useful for products with new technology and complex projects where the requirements are not clearly understood at the early stage.

Incremental Prototyping. This technique breaks the final product into smaller parts, and each small part is developed as an individual prototype. The individual prototypes are then united into a final product as per customer requirements. This method helps in reducing the feedback time between the customer and the development team.

Extreme Prototyping. This technique is specifically used for web development. This method involves three phases (i) The basic prototype consisting of the HTML page is created (ii) data processing simulation using services layer and (iii) implementation of the services and integration of the final prototype.

1.6. BEST PRACTICES OF PROTOTYPING

Few things should necessarily be considered during the prototyping process:

- Prototyping can be used when the requirements are unclear
- Planned and controlled prototyping should be executed for better result
- Regular meetings are to be conducted to complete the project on time
- The user and the designer should have knowledge on the prototype
- Approval is mandatory for every stage of prototyping as it proceeds to the next step
- The methodologies should be clearly discussed

1.7. IMPORTANCE OF PROTOTYPES/PROTOTYPING FOR NEW PRODUCT DEVELOPMENT

- Prototypes serve as a common platform in communicating and understanding the concept of external stakeholders and within the team.
- Prototypes enable testing and refining the product design functions by reducing the errors during the design stage.
- A prototype helps in thinking, planning, designing and experimenting the product and reduces uncertainties.
- Prototyping encourages the selection of suitable materials for a product by considering the various possible factors.
- Prototypes help to attract potential investors.
- Prototypes give a thorough understanding of the product to all the departments in an organization.

- Prototyping helps in determining the most efficient manufacturing methods.
- Prototyping explores various concepts, reduces technical uncertainty and supports decision making.
- Prototype enables to manufacture the final product by bringing in the various components together.
- Prototyping assists in scheduling the product development process.

1.8. HISTORICAL DEVELOPMENT OF RAPID PROTOTYPING

The global competitive market environment demands advanced products with high quality that are cheaper. The product is expected to be made available to the customers at a faster rate than the competitors. The complexity of the products is also increasing drastically and it creates a demand for advanced technologies to solve critical manufacturing issues. The rapid technological growth demands evolution of new tools, approaches and technologies starting from the design phase to the implementation phase. The rapid growth in computer technology in manufacturing industries like Computer-aided Manufacturing (CAM), Computer-aided Design (CAD), and Computer Numerical Control (CNC) machine tools encouraged the development of rapid prototyping in industrial applications. The development of rapid prototyping has undergone three phases namely manual prototyping, virtual prototyping and rapid prototyping. A brief comparison of the three phases is shown in Table 1.1

Phase I. Manual Prototyping

The first phase of prototype development started centuries ago to convert an idea or dream into a prototype that later became reality such as parachutes, airplanes and even robots. A wide range of craft-based materials like paper, cardboard, foam, wax clay, etc. was used to build static mock-ups. During this phase developing the prototypes were complicated and normally took a long period depending upon the complexity of the product. Engineers used manual tools to create prototypes and found it difficult to demonstrate the customer expectations in a single prototype. They had to develop separate prototypes for different requirements from the customers which in turn consumed lot of time and money. Therefore the possibility of involving all the stakeholders during the iterative process is very less. The traditional methodologies include clay model, carving from wood, bending wire meshing, carving from foam and milling from a block of plastic or aluminum.

Phase II. Virtual Prototyping

The second phase of prototyping is an analytical model of the virtual prototype. A virtual prototype is an analytical model with some design aspects that helps the engineer to predict the product behavior, without developing the physical prototype. Virtual prototyping started with the development of wireframes which is an approximate illustration of a three-dimensional object in the form of lines. Later, the wireframes were enhanced by adding surfaces and solid models for visualization enhancement and analysis. With the availability of advanced computer tools, solid models can now be tested, analyzed and modified similar to that of the physical prototypes with the help of Finite Element Analysis software. Mathematical model-based design predicts the dynamic behavior of complex products accurately. Several iterations in terms of design can be easily carried on the virtual models by changing the parameters. Analytical prototyping methods such as computer aided design, computer-aided modeling, kinematics and multi-body dynamics, finite element analysis, electronic circuit design, virtual reality and topological modeling are employed for prototyping. Virtual prototyping finds its applications in testing and optimization, control system design, and connecting the virtual world with the real world. Virtual prototyping is also used in applications like kinematic/dynamic analysis based on certain assumptions and hence there is no assurance that the virtual prototype is free from errors. Limitations also arise concerning the errors in data collected and applied in virtual prototyping for analysis. Often, virtual prototyping may not be able to assess the final presentation of a product. Computer-aided methods like computer-aided design, computer-aided manufacturing uses 3D solid models for machining with the help of CNC was considered as the frontrunner for rapid prototyping technologies.

Phase III. Rapid Prototyping

Prapid prototyping process emerged in the 1980s and is an advanced manufacturing process that generates three-dimensional components, models, or assembly with the aid of computer-aided design (CAD) digital image.

Table 1.1 Comparison of the three prototyping phases

	Manual Prototyping	*Virtual Prototyping*	*Rapid Prototyping*
Phase	First Phase	Second Phase	Third Phase
Evolution	Traditional practice for centuries	Mid-1970s	Mid1980s
Nature of prototyping	Natural prototyping technique like clay model, carving from wood, bending wire meshing, carving from Styrofoam, milling from a block.	Analytical model with some design aspects to predict the product behavior without developing the physical prototypes.	Generates three dimensional parts with the help of computer aided design (CAD) digital image
Methodology	Prototyping as a skilled crafts is a manual process	Software based analysis	Computer aided design software integrated with manufacturing techniques.
Testing of prototypes	Tested using standard testing equipments	Virtual prototype are stressed, simulated, and tested with exact mechanical and other properties	Hard prototype can be rested using standard testing procedures
Skills required	Manual skills and knowledge on drawings	Software skills and knowledge for testing and defining the constraints	Design skills
Period of prototyping	Takes more time to manufacture	Depends on the complexity of the model	Less time

Modification is carried with the help of computer-aided design resulting in a precise physical 3D object prototype. Hideo Kodama from Japan and Charles Hull from the USA in 1986 developed stereolithography, the first rapid prototyping technology capable of printing in three dimensions. The main objective of rapid prototyping is to fabricate prototypes at a faster rate to speed up the product development process. Rapid prototyping produces physical prototypes for testing based on the processes like layered manufacturing where the parts are built in a layered manner from the bottom. Rapid prototyping makes use of printing technology where a layer of material is printed on a substrate. Various layers are stacked together to form a 3-D product. The creation of part, model, or assembly is usually carried by using additive manufacturing commonly known as 3D printing. Additive manufacturing technology involves three-dimensional components fabricated from the computer-aided design image by adding materials layer after layer. The layer-by-layer fabrication is expressed in different names known as layered manufacturing, rapid tooling, freeform fabrication, direct writing, additive manufacturing, 3D printing, biofabrication, etc. Additive manufacturing is the collective name for all processes that adds successive layers of material, as against subtractive manufacturing that involves removal of materials from the workpiece. Modern rapid technologies find their applications in industries like manufacturing, design, aerospace, automotive, biomedical, coining, jewelry.

1.9. NEED FOR RAPID PROTOTYPING

The rapid prototyping method of product development facilitates engineers to finalize the design iterations faster and make the products available to the customers quickly. Modern manufacturers use computer-aided design technologies to develop physical models for analysis and get them fabricated using technologies like high-speed machining, moulding, casting, extruding, additive manufacturing/ 3 D printing techniques. Additive manufacturing plays an important role in the following aspects:

Faster product development. Rapid prototyping creates physical prototypes in combination with virtual prototyping at a faster rate and plays a vital role in product development process.

Part complexity. Complex parts/components including sculptured shapes for functional as well as aesthetic aspects can be designed and fabricated.

Reduction/combining of parts. The number of physical parts can be reduced by combining the various features into a single part without any functional loss thereby reducing the machining time, wastage, time, fasteners, and complexity in assembly.

Cost-saving. Minimizing the system design, manufacturing process and proper tooling decrease the manufacturing cost by reducing the parts, assembly, and inventory expenses.

Reduction in labor. Labor requirements can be minimized by effective machine setting, automatic machining, reduction in the inspection process, assembly, etc.

Reduction of wastage. Waste disposal costs are reduced because of effective design changes and proper machining process.

Improvement in marketing. Rapid prototyping improves marketing in terms of (i) reduced marketing risk (*ii*) products contributing with respect to price/performance (*iii*) improvement in product reliability (*iv*) diversity of the product.

Consumer satisfaction. Since customers are involved in the prototyping process, consumer can receive products as per their requirements at lower prices.

Systematic approach. Rapid prototyping involves a systematic approach starting from the early design stage to the final product verification phase thereby improving the accuracy of the product.

Feedback. Manufacturers receive feedback at all stages of prototyping from their stakeholders and helps improving the overall efficiency of production and sales.

1.10. FUNDAMENTALS OF RAPID PROTOTYPING

Rapid prototyping technique converts three-dimensional CAD data into a physical prototype as per the drawing. The stages involved in Rapid Prototyping process are shown in Fig.1.2 It involves five stages namely CAD solid modeling, conversion of CAD model to STL, preprocessing, model building and post-processing.

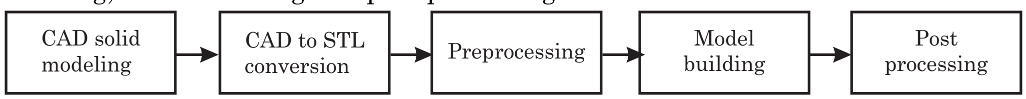

Fig. 1.2. Block diagram of Rapid prototyping process

CAD solid modeling: CAD modeling is the first stage in rapid prototyping process. This process starts by developing a three-dimensional CAD model that represents the design of prototype. Standard modeling softwares can be used for developing the CAD model. The designer can use an existing CAD file directly or modify an existing CAD file or can create a new CAD model for prototyping. The developed CAD model should be in a standard solid model format for further processing.

Conversion of CAD model to STL. The developed CAD file has to be converted into an STL file format. The STL file illustrates the surface geometry of a 3D solid model in the form of triangular surfaces assembled without representation of any color, texture, or other model characteristics (Fig.1.3). To have better accuracy, the number of triangles has to be higher and the size must be smaller. The STL file is generally an abbreviation of **ST**ereo**L**ithography and sometimes it is also referred to as "Standard Triangle Language". STL file format is supported by many CAD software and is used for rapid prototyping, 3D printing, and computer-aided manufacturing.

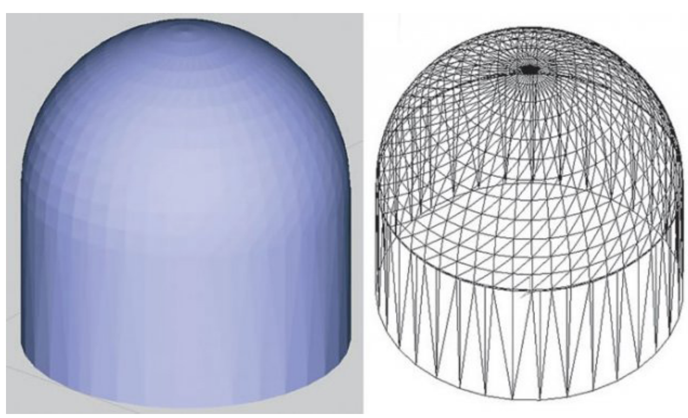

Fig. 1.3. CAD Model to STL file conversion

Preprocessing. The created STL file has to be organized differently for different rapid prototyping systems. Some systems accept the STL file format directly, but it is not the same in all systems and therefore preprocessing is essential. Preprocessing is the process of verifying the STL file and slicing the developed STL model into several layers having a thickness in the range of 0.01 mm to 0.7 mm. The slicing software enables designer to regulate the size, location and orientation of the model. Orientation helps in determining the time required to develop the model and to set up the machine parameters. The slice file format is then transferred to the rapid prototyping system.

Model building. Once the final slice file is transferred to the rapid prototyping system model building takes place by the tool patterns generated. Building of the physical model will take place by any one of the fabricating methods. Rapid prototyping develops models by building layers using materials like wax, acrylonitrile butadiene styrene, polymers, liquid resin, filament, metals, ceramics, etc. Materials may be in the form of liquid or solid depending upon the process.

Post-processing. Post-processing takes place once the model is being built. During this process, the product is removed from the machine carefully and the finishing process is carried out and tested for its performance. The results after testing are evaluated and checked whether it satisfies the requirement and if it satisfies the requirement then the process is stopped. Otherwise, it undergoes further refining in the CAD until requirements are met.

1.11. ADVANTAGES OF RAPID PROTOTYPING

Prototyping and rapid prototyping guarantees the following benefits to its stakeholders :

- Ability to explore the concepts at a faster rate.
- Reduction in time and cost needed to develop the required molds and tools
- Reduction in overall product development and finished product manufacturing cost
- Ability to manufacture small size components having complex geometries
- Design changes can be carried out instantaneously without modifying the entire process
- Minimize wastages during prototype building and product manufacturing
- Ability to manufacture realistic 3D components with great accuracy
- Identification of design flaws at any stage of the process
- Reduction of major risk involved in manufacturing
- Effective evaluation and testing of the product before production
- Improved and increased user involvement in the feedback mechanism
- Ability to communicate concepts concisely and effectively to all the departments
- Ability to thoroughly test and refine a concept
- Effective feedback mechanism at all stages from design to production

1.12. LIMITATIONS OF RAPID PROTOTYPING

- Some rapid prototyping processes are still expensive and not economical
- Material properties like surface finish and strength cannot be matched
- Error, confusion from the customers during feedback has an impact on the finished product
- Skilled labour is required
- Misunderstanding of customer objectives by the manufacturers leads to chaos
- May not be applicable for all kind of materials
- Improper planning leads to an increase in complexity of the system
- Incomplete inputs in the design stage Lead to inadequate problem analysis

1.13. COMMONLY USED TERMS IN RAPID PROTOTYPING

Rapid Prototyping (RP). Rapid prototyping is a collection of fabrication methods that fabricate physical models/components at a faster rate using a 3D computer-aided design model/data.

Additive Manufacturing (AM). Additive manufacturing is the industrial standard name for 3D printing that builds a three-dimensional part by depositing/adding materials layer by layer as per the 3D CAD model.

3D Printing. 3D printing is the most common name used by the media and the general public to represent additive manufacturing. The 3D component is fabricated by adding materials layer by layer from the CAD model data.

Subtractive Manufacturing. Subtractive manufacturing is the process by which 3D components are fabricated by subtracting/cutting/removing material from a solid block by machining processes like drilling, milling, turning, CNC machining.

STL file. STL **(**StereoLithography) file is the most common file format for 3D printing. It is the triangular representation of the surface for three-dimensional solid models. It is an interface between CAD software and prototyping equipment.

Instant Manufacturing. Instant manufacturing is the process in which the machine produces 3D parts directly from the three-dimensional CAD digital files.

Desktop manufacturing. Desktop Manufacturing sometimes called personal fabrication is manufacturing the three-dimensional prototypes using a personal computer to drive the machine/3D printer.

Direct Digital Manufacturing (DDM): Direct Digital Manufacturing is a process that directly manufactures the final product and not the prototype developed from a CAD file using additive manufacturing techniques.

Solid Freeform Fabrication (SFF). Solid freeform fabrication represents a category of non-conventional manufacturing techniques in which solid parts are developed by depositing one cross-sectional layer of material over the other without manufacturing process planning, tooling, or fixtures. Methods like Stereolithography, Fused Deposition Modeling, Selective laser sintering comes under solid freeform fabrication. The name solid is used because the initial state of the material may be liquid, powder, or laminates and the result is a 3D solid object.

Computer-Aided Design (CAD). Computer-Aided Design is a computer technology that makes use of a computer to create the design model of a part defined by geometrical parameters.

Photopolymer. Photopolymer is a kind of polymer that changes its physical or chemical properties when it is exposed to light, often in the ultraviolet spectrum.

Fused Deposition Modeling (FDM). Fused deposition modeling also known as Fused Filament Fabrication (FFF) is an additive manufacturing process that develops a 3D object directly from a computer-aided design data by depositing the liquefied thermoplastic filament extruded via a nozzle.

Selective Laser Sintering (SLS). Selective laser sintering is an additive manufacturing process that makes use of a laser to sinter the powdered materials to create a three-dimensional solid object.

Stereolithography (SLA). Stereolithography is an additive manufacturing process that makes use of a computer-controlled laser to create a solid model by converting the liquid photopolymers resin into the required solid object.

1.14. FUNDAMENTAL AUTOMATED MANUFACTURING PROCESSES

Automated processes are fundamentally classified into three categories namely additive manufacturing, subtractive manufacturing and formative manufacturing. Additive manufacturing deals with the process of adding materials layer by layer while subtractive manufacturing is related to the removal of materials by machining. In formative manufacturing, the materials in the form of liquid or semi-solid are passed into the desired shape die by casting, injection molding, compressive sintering, metal forming, etc. The Schematic representation of the fundamental manufacturing processes is represented in Fig.1.4.

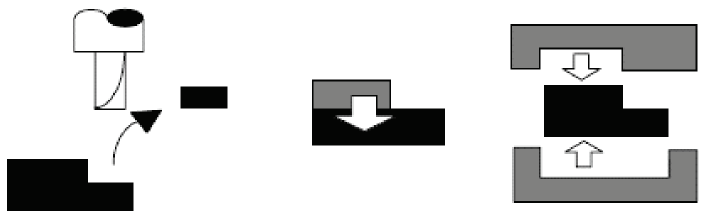

Fig. 1.4. Schematic representation of manufacturing processes

1.15. ADDITIVE VS SUBTRACTIVE MANUFACTURING

In the past few decades, most of the reliable manufacturing processes fall into any one of the two categories namely additive manufacturing and subtractive manufacturing. Additive and subtractive manufacturing are technologically developing at a rapid rate by which the products, parts and prototypes are made. A comparison between additive manufacturing and subtracting manufacturing is shown in Table 1.2.

Additive Manufacturing: Additive manufacturing is the process of building a part by adding material layer by layer using various additive manufacturing processes. Additive manufacturing technique develops parts from CAD model data by slicing the model into layers with the help of automated software. The material is then deposited layer over layer by melting, fusing and curing depending upon the manufacturing processes. Additive manufacturing needs some cleaning and finishing process to achieve their final desired shape and appearance. The commonly used additive manufacturing process includes stereolithography, selective laser sintering, fused deposition modeling, selective laser melting, electron beam melting, etc. Materials like plastics, nylon, soft and hard metals can be used for developing components by additive manufacturing.

Subtractive Manufacturing. Subtractive manufacturing is the process by which the required shape is obtained by removing materials through processes like drilling, milling, grinding, etc. Machining can be carried out manually using conventional machines or driven and controlled by Computer Numerical Control (CNC). In CNC machining the virtual model designed using CAD software serves as the input for fabrication and machining is carried by computer-aided manufacturing, with or without human assistance/interaction. Subtractive manufacturing Includes a variety of machining processes like conventional machining, CNC machining, laser cutting, electrical discharge machining, water jet cutting, abrasive jet machining, etc. Subtractive manufacturing is capable of machining plastics, metals, fabrics, wood, composites, etc. to the desired shape.

Additive Manufacturing

About the book

This book presents a theoretical and practical overview of several aspects of additive manufacturing. Furthermore, this books discusses about how the technology of additive manufacturing has evolved beyond the initial intent of prototyping.

Disseminating information about latest trends and developments in manufacturing optimization, this books aims to be a one-stop resource for the readers to stay informed and ahead of the curve.

Oriented towards engineers, designers, students and researchers, this book also supports product developers facing challenges in implementing additive manufacturing technology.

This book explains the working principles, components, machining characteristics/process parameters, advantages and limitations of additive manufacturing.

About the Author

Dr. ***K. Ravi Kumar*** is currently working as Professor in the Department of Mechanical Engineering at KPR Institute of Engineering and Technology, Coimbatore, India. He completed his B.E. - Mechanical Engineering in 2001 from Bharathiyar University and M.E. - Production Engineering in 2002 from Annamalai University, Tamil Nadu. He received his Ph.D degree from Anna University in the area of Composite Materials in 2013. He is into the teaching profession since 2003 and has handled engineering education in various capacities. His areas of research include composite materials, unconventional machining, optimization, characterization and additive manufacturing. He has received grants from funding agencies like ICMR, SERB, Anna University etc., for conducting seminars, Conferences, workshops and FDPs. He has published more than 30 research articles in SCI/Scopus indexed journals and also presented and published more than 20 papers in various International and National Conferences. He has also published five patents to his credit. His publications have widely been cited by researchers. He is an active reviewer and editorial board member for various international journals that includes Elsevier, Springer, Taylor & Francis, SAGE, and Deguyter Publications. Presently, seven scholars are pursuing their Ph.D programs under his guidance. He is also an active member of various professional societies namely IE (I), ISTE and SAE.

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