Chapter 8: Rapid-prototyping Processes

Introduction. In the development of a new product, there is invariably a need to produce a sample, or **prototype,** of a designed part or system before allocating large amounts of capital to new production facilities or assembly lines. The main reasons for this need are that the capital is very high and production tooling takes considerable time to prepare. Consequently, a working prototype is needed for design evaluation and **troubleshooting** before a complex product or system is ready to be produced and marketed.

A technology that speeds up the iterative product-development process considerably is the concept and practice of **rapid prototyping** (RP), also called **desktop manufacturing, digital manufacturing,** or **solid free-form fabrication.** Rapid-prototyping processes can be classified into three major groups: 1. **Subtractive,** removing material from a workpiece that is larger than the final part, 2. **Additive,** building up a part by adding material incrementally and 3. **Virtual,** using advanced computer-based visualization technologies.

Subtractive Processes. This approach requires skilled operators and uses a series of material removal by **machining** and **finishing** operations until the prototype is completed. When a prototype is required only for the purpose of shape verification, a soft material (usually a polymer or wax) is used as the workpiece, in order to reduce or avoid any machining difficulties. The material intended for use in the actual application also may be machined, but it may be more time consuming. Depending on part complexity and the level of machining capabilities in a plant, prototypes can be produced in a few days to a few weeks.

A. Fill in the blanks with the following words.

manufacture, additive, instructions, slices, CAD

Additive Processes. Additive rapid-prototyping operations all build parts in layers. In order to visualize the methodology employed, it is beneficial to think of the construction of a loaf of bread, by stacking and bonding individual **………………** of bread on top of each other (hence the term ………………..). The main difference between the various additive processes lies in the method of producing the individual slices, which are typically 0.1–0.5 mm thick, although they can be thicker in some systems.

All additive operations require **dedicated** software. As an example, note the solid part shown in Fig. 1a. The first step is to obtain a ………... file description of the part; the computer then constructs slices of the three-dimensional part (Fig. 1b). Each slice is analyzed separately, and a set of **………………..** is **compiled** in order to provide the rapid-prototyping machine with detailed information regarding the ………………. of the part. Figure 1d shows the paths of the extruder in one slice, using the fused-deposition-modeling operation.

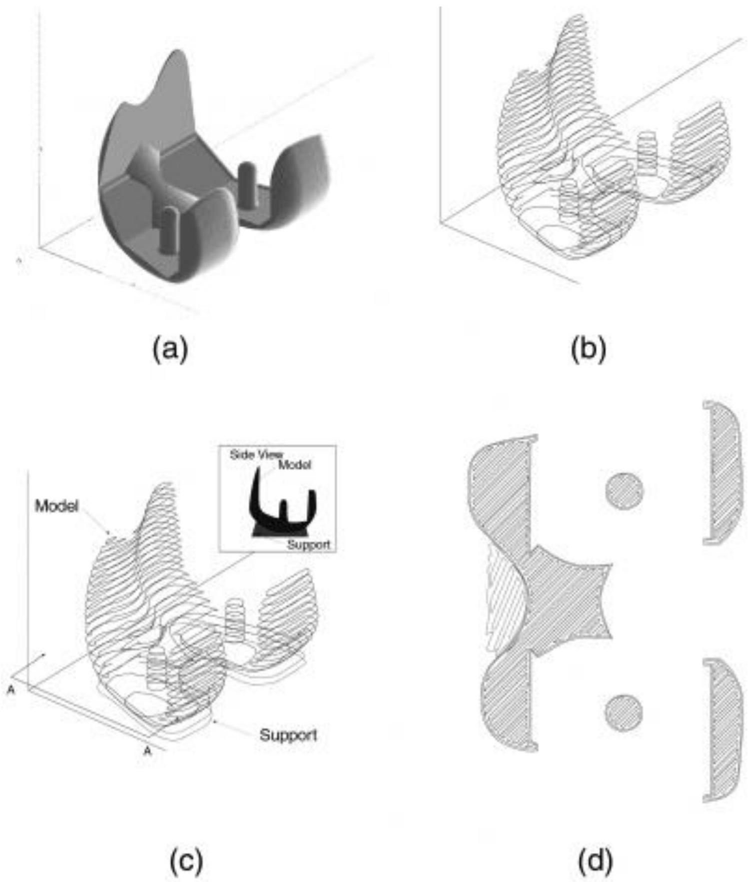

Fig. 1 The **computational** steps in producing a **stereolithography** (STL) file; (a) Three-dimensional description of part. (b) The part is divided into slices: only 1 in 10 is shown. (c) **Support** material is planned. (d) A set of tool directions is determined to manufacture each slice. Also shown is the extruder path at section A–A from (c) for a fused-deposition modeling operation.

Fused-deposition Modeling. In the fused-deposition-modeling (FDM) process (Fig. 2), a **gantry-robot** controlled **extruder** head moves in two principal directions over a table, which can be raised and lowered as required. The extruder head is heated, and extrudes polymer **filament** at a constant rate through a small **orifice**. The head follows a predetermined path (see Fig. 1d); the extruded polymer bonds to the previously **deposited** layer. When the first layer is completed, the table is lowered so that subsequent layers can be superimposed over the first layer. When the part is finished, it can be easily removed from the base. The layers in an FDM model are determined by the extrusion-die diameter, which typically ranges from 0.05 to 0.12 mm. This thickness represents the best achievable tolerance in the vertical direction. In the x –y plane, dimensional accuracy can be as fine as 0.025 mm as long as a filament can be extruded into the feature.

Stereolithography. This process (Fig. 3) is based on the principle of **curing** (hardening) of a liquid photopolymer into a specific shape. A **vat**, containing a mechanism whereby a platform can be lowered and raised, is filled with a photocurable liquid-acrylate polymer. At the highest position of the platform (a in Fig. 3), a shallow layer of liquid exists above the platform. A laser, generating an **ultraviolet** (UV) beam, is focused upon a selected surface area of the photopolymer, and then moved around in the x –y plane. The beam cures that portion of the photopolymer, and thereby produces a layer of the solid body. The platform is then lowered sufficiently to cover the cured polymer with another layer of liquid polymer, and the sequence is repeated. The process is repeated until the part is completed.

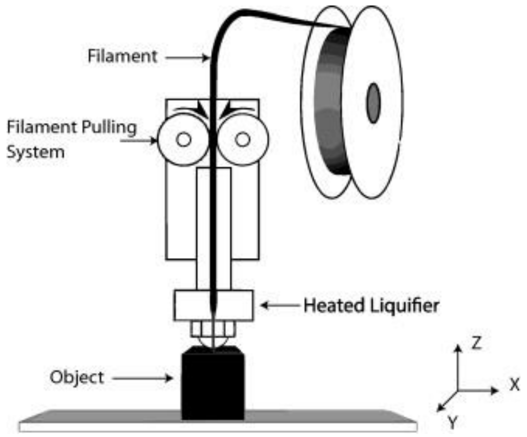

Fig. 2 Schematic illustration of the FDM process.

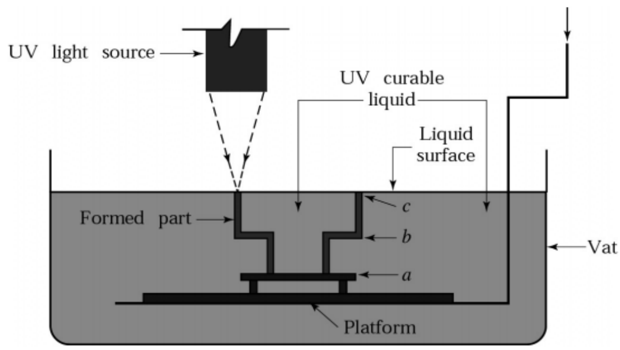

Fig. 3 Schematic illustration of the stereolithography process.

B. Fill in the blanks with the following words.

powder-feed, solid, sintering, curing, part-build

Selective Laser Sintering. Selective laser sintering (SLS) is a process based on the ……………….. of nonmetallic or, less commonly, metallic powders selectively into an individual object. The basic elements in this process are shown in Fig. 4. The bottom of the processing chamber is equipped with two cylinders:

1. A …………………… cylinder, which is raised incrementally to supply powder to the part-build cylinder, through a roll mechanism

2. A ……………… cylinder, which is lowered incrementally as the part is being formed.

A thin layer of powder is first deposited in the part-build cylinder. Then a laser beam, guided by a process-control computer using instructions generated by the three-dimensional CAD program of the desired part, is focused on that layer, tracing and sintering a particular cross-section into a ……………….. mass. The powder in other areas remains loose, but it supports the sintered portion. Another layer of powder is then deposited; this cycle is repeated again and again until the entire three-dimensional part has been produced. The loose particles are shaken off, and the part is recovered. The part does not require further ………………, unless it is a ceramic, which has to be fired to develop strength.

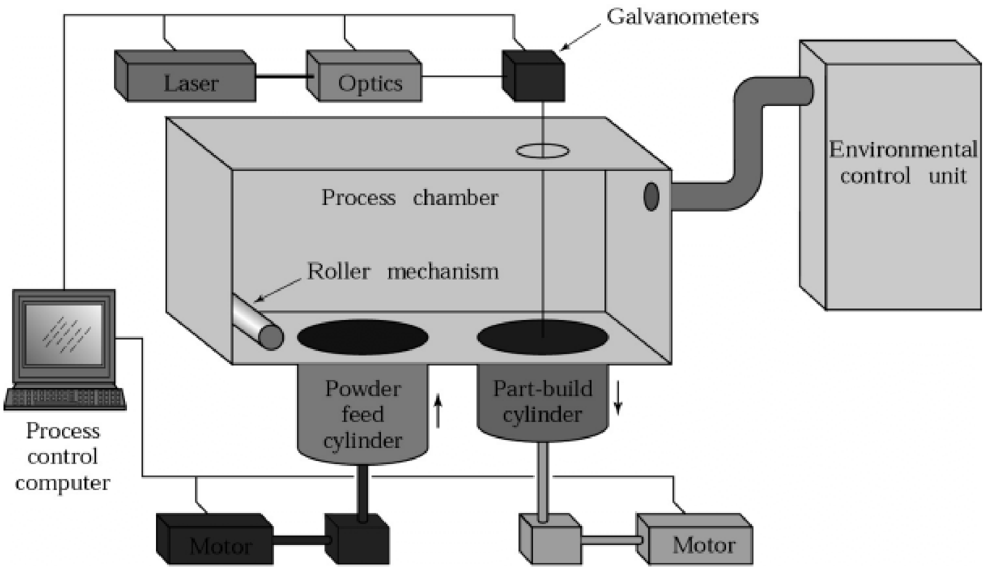

Fig. 4 Schematic illustration of the selective laser sintering process.

Virtual Prototyping. Virtual prototyping is a purely software form of prototyping; it uses advanced graphics and virtual-reality environments to allow designers to examine a part. This technology is used by common, conventional CAD packages, to render a part so that the designer can observe and evaluate it as drawn.

The simplest forms of such systems use complex software and three-dimensional graphics routines, to allow viewers to change the view of the parts on a computer screen. More complicated versions use virtual-reality headgear and gloves with appropriate **sensors**, to let the user observe a computer-generated prototype of the desired part in a completely virtual environment.

Self-replicating Machines. With the expiration of patent protection for many of the rapid prototyping processes, a movement, based on open-source sharing of software and machine designs, has now developed. Taking advantage of Internet-based data-sharing tools, inexpensive machines, based on FDM, have been developed and are available as **kits**, fully constructed, or with merely the plans for construction available for download.

Extending the **open-source** software traditions to hardware have encouraged the development of self-replicating machines, where the rapid prototyping machine creates parts that are used to produce another identical rapid prototyping machine. Not all parts are replicated (control hardware and metal structural parts, for example, are separate items), but up to 60% of the components can be produced. This has led to a proliferation of low-cost rapid prototyping machines. For example, RepRaps can be constructed from components that cost a few hundred dollars unassembled, Thing-o-Matic kits cost around $1000, and a complete Cube is around $1300.

Direct Manufacturing. While extremely beneficial as a demonstration and visualization tool, rapid-prototyping processes also have been used as a manufacturing step in actual production. There are two basic methodologies used:

1. Direct production of engineering metal, ceramic, and polymer components or parts, by rapid prototyping

2. Production of tooling or patterns by rapid prototyping, for use in various manufacturing operations

Not only are the polymer parts, obtained from various rapid-prototyping operations, useful for design evaluation and troubleshooting, occasionally these processes also can be used to manufacture parts directly, referred to as direct manufacturing. Thus, the component is generated directly to a near-net shape, from a computer file containing part geometry.

C. Fill in the blanks with the following words.

modular, pattern, cycle time, lead times, insert, shrinkage

Rapid Tooling. Several methods have been devised for the rapid production of tooling (RT) by means of rapid-prototyping processes. The advantages to rapid tooling include: **1.** The high cost of labor and short supply of skilled patternmakers can be overcome. **2.** There is a major reduction in ……………… . **3.** Hollow designs can be adopted easily so that lightweight castings can be produced more easily. **4.** The integral use of CAD technologies allows the use of **………………** dies, with base-mold tooling (match plates) and specially fabricated inserts; this technique can further reduce tooling costs. **5.** Chill- and cooling-channel placement in molds can be optimized more easily, leading to reduced …………………… . **6.** ………………….. due to solidification or thermal contraction can be compensated for automatically, through software to produce tooling of the proper size and, in turn, to produce the desired parts. The main shortcoming of rapid tooling is the potentially reduced tool or ……………… life, as compared to those obtained from machined tool and die materials, such as tool steels or tungsten carbides.

The advantage of rapid tooling is the capability to produce a mold or a mold ……………… that can be used to manufacture components, without the time lag (typically several months) traditionally required for the **procurement** of tooling. Moreover, the design is simplified, because the designer need only analyzes a CAD file of the desired part; software then produces the tool geometry and automatically compensates for shrinkage.

***CASE STUDY.* Invisalign® Orthodontic Aligners**

The Invisalign system, made by Align Technology, Inc, consists of a series of aligners, each of which the person wears for approximately two weeks. Each aligner consists of a precise geometry that incrementally moves the teeth to the desired positions. Because the aligners can be removed for eating, brushing, and flossing, most of the drawbacks of conventional braces are eliminated. Furthermore, since they are produced from a transparent plastic, the aligners do not seriously affect the appearance of the person's teeth.

The Invisalign product uses a combination of advanced technologies in the production process, shown in Fig. 5. The treatment begins with an orthodontist, or a general dentist, making a polymer impression of the patient's teeth. These impressions then are used to create a three-dimensional CAD representation of the patient's teeth. Proprietary CAD software then assists in the development of a treatment strategy for moving the teeth in an optimal manner. Once the treating orthodontist has approved the treatment plan and it has been developed, the computer-based information is used to produce the aligners. The Align process uses a stereolithography machine that produces patterns of the desired incremental positions of the teeth. A sheet of clear polymer is then thermoformed over these patterns to produce the aligners, which are then sent to the treating orthodontist. With the doctors' supervision, patients are instructed to change the next set of aligners every two weeks.

Fig. 5 An aligner for orthodontic use, manufactured by a combination of rapid tooling and thermoforming.

Video: Rapid Prototyping and Rapid Tooling (Click this link or scan the QR code).

D. Translate the following sentences into English.

۱. ماشینکاری و پرینت سه بعدی به ترتیب جزء روش‌های برداشت و افزودن نمونه‌سازی سریع هستند.

۲. هواپیمای بوئینگ ۷۷۷ یک مثال خوب از محصولات پیچیده‌ای است که بدون ساختن نمونه اولیه فیزیکی تولید شده‌اند.

۳. در روش مدلسازی لایه‌نشانی ذوبی، اکسترودر فیلامنت پلیمری را ذوب نموده و آنرا در مسیرهای از پیش‌تعریف شده در سطح مقطع قطعه (یک لایه از قطعه) می‌ریزد.