IUBAT Review
A Multidisciplinary Academic Journal

Arijit Sen. 2017. "Techniques of Rapid Prototyping and comparison with Computer Numerically Controlled Machining." *IUBAT Review* 1 (2): 69-76. iubat.edu/journal

Techniques of Rapid Prototyping and Comparision with Computer Numerically Controlled Machining

Arijit Sen

Department of Mechanical Engineering
IUBAT—International University of
Business Agriculture and Technology
Uttara, 1230

ABSTRACT: *Rapid prototyping is a developing technology in product design and manufacturing. This paper describes the various techniques of rapid prototyping and compares the cost and surface quality of prototypes produced in fused deposition modelling and 3D printing with that of CNC (Computer Numerically Controlled) machining. It was found that the fused deposition modelling method produces the prototype with the best surface quality and CNC machines produce the prototype at least cost.*

KEYWORDS: *Fused deposition modelling, Rapid prototyping, 3D printing.*

Introduction

Rapid prototyping is an expanding field in the design and manufacturing industry. Prototyping is the task between the design and manufacturing phase of a product. It ensures the designers that the product is going to conform to the design specification and also reveals the hidden defects, if any exists that cannot be detected either by design drawing or by 3D CAD model. The traditional way of making a prototype is material removal from a block, either by using hand tools or with the help of machine tools. To build prototypes with these processes takes much time; however, with the development of CNC machining the time required has been reduced to some extent. A new technique of making prototype, 'Rapid Prototyping' (RP), has developed since the 1980s. Rapid Prototyping is "a generic term for a number of technologies that enable components to be made without the need for conventional tooling in the first instance or indeed without the need to engage the services of skilled model-makers" (Upcraft and Fletcher, 2003). The input of a rapid prototyping process is a 3D CAD model, which can be visualised only, and the output, which is the physical replica of that 3D CAD model. Rapid prototyping will eventually move into the heart of the manufacturing process and end use parts will be made by these techniques (Dickens, 2001). The growing popularity of this process can be found by looking at the increasing market volume of rapid prototyping machines, from US$1.5 billion in 2011 to US$4.2 billion in 2015 (Muller and Karevska, 2016).

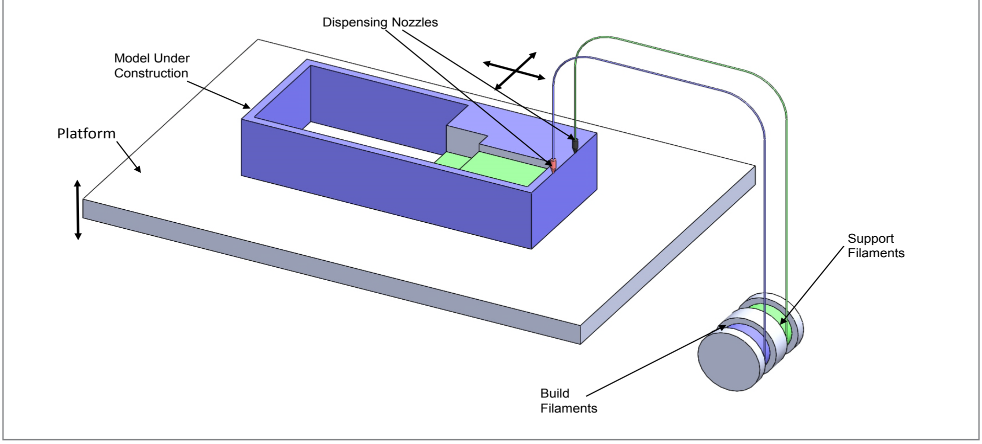
Different Techniques of Rapid Prototyping

The conventional prototyping process is subtractive: it removes material from a block. In contrast, rapid prototyping is an additive process: it builds the model by adding successive layers. In order to form such a model, 3D CAD models are sliced into layers using software in the prototyping machine. Accumulation of those layers results into the desired prototype. There are different techniques of rapid prototyping, such as a) fused deposition modelling, b) stereo lithography, c) selective laser sintering, d) ballistic particle manufacturing, e) 3D printing, f) laminated object manufacturing, and g) film transfer imaging technology. In addition, a combination of additive and subtractive processes for making more accurate prototypes, called hybrid prototypes, is also available.

Fused Deposition Modelling

Figure 2.1 shows a schematic view of the fused deposition modelling process. it includes a head that can move in X and Y directions simultaneously, and a table which can move in Z direction. The head deposits molten material on a board, which is placed upon the table, to create a layer. After completing one layer the table goes slightly down and the next layer is built upon the previous layer in the same way. This process continues until the full model is produced. To build an overhanging portion of a part it needs a support which is built in the same way as the model, using a different material.

Figure 2.1: Schematic view of fused deposition modelling.

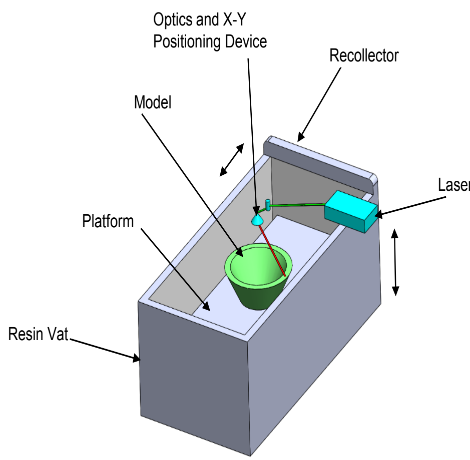


The model and the support are made simultaneously, and after finishing the model construction, the support is removed. Two heads work together – one is used for building the actual model and another for building the support, if required. The material used for making the model is generally thermoplastic or wax; the support material is generally weaker than the model material, and can be broken or easily dissolved. A honey-comb profile is used for making the support, to reduce the consumption of material and hence lower the cost.

Stereo Lithography

In this process, the layers of the model are built by curing resin, generally using an ultraviolet laser beam. A laser head can move in X and Y directions freely, and a table can move in Z direction. The table is located inside the container of resin. Figure 2.2 shows a schematic illustration of this method in which the table is kept initially in a position such that a very thin layer of resin exists on the table.

Figure 2.2: Schematic view of stereo lithography modelling.



This layer is then cured by laser beam to generate the first layer of the model. The table is then slightly lowered and the next layer is built. By continuing this process many times, the final model is obtained. Afterwards, the model is treated in an ultraviolet oven. The overhanging portion needs support, which is removed later. The materials used are a mixture of acrylic monomers, oligomers (polymer intermediates) and a photo initiator in this process (Kalpakjian and Schmid, 2006). In this process, the uncured resin can be reused.

Selective Laser Sintering

Selective laser sintering also uses a laser beam but instead of using resin to form the prototype, it uses a powder material. As with other methods, a laser head can move freely in the XY plane and a table can move vertically as shown in figure 2.3.

The materials used for this process are powder forms of polymers such as ABS, PVC, nylon, polyester, polystyrene and epoxy, wax, metal and ceramic – with an appropriate binder (Kalpakjian and Schmid, 2006). The unused powder can be used again.

Ballistic Particle Manufacturing

Ballistic particle manufacturing uses an ink jet head able to move along three axes. This ink jet head ejects small droplets of material on a surface to build the layers of a model. A piezoelectric pump is used to eject droplets. Materials used to support the overhanging portions of the prototype are plastic, ceramic, metal and wax (Kalpakjian and Schmid, 2006).

Three-Dimentional Printing

The 3D printing process uses powder and glue to build the model. It uses the principle of the ink jet printer. However, the printer head sprays glue instead of ink.

Figure 2.3: Schematic view of selective laser sintering

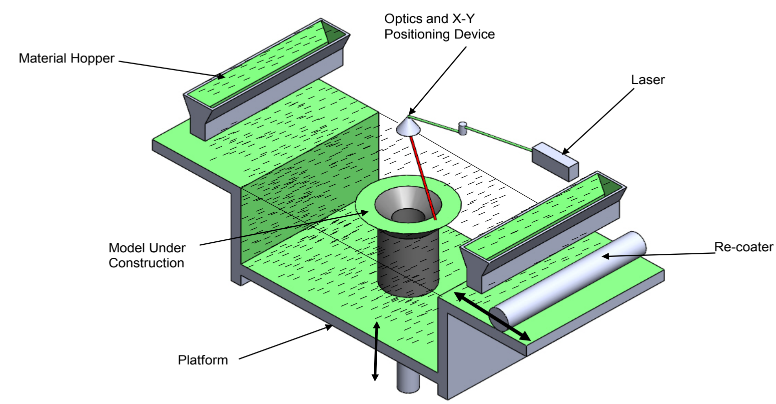


Figure 2.5: Schematic view of three-dimensional printing

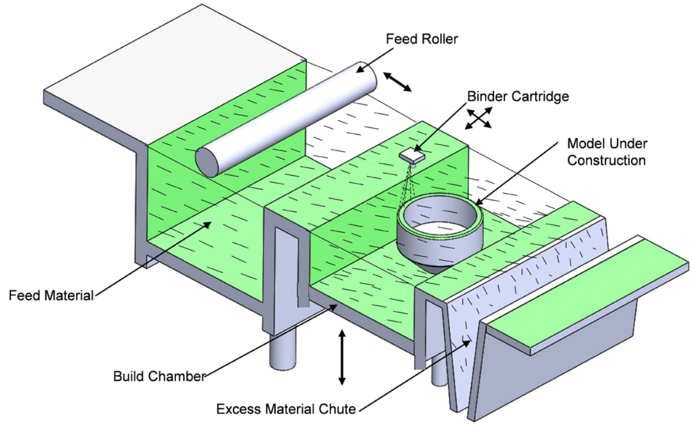
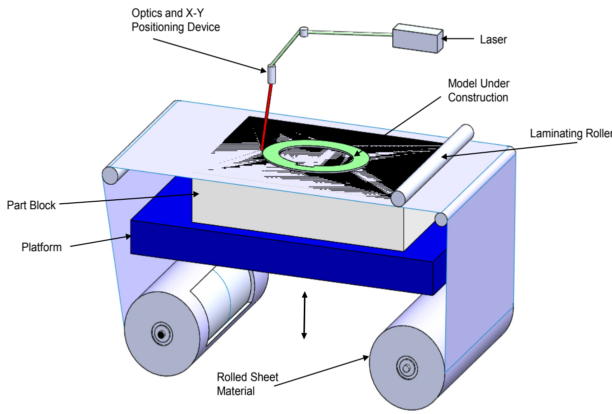


Figure 2.5 is a schematic view of the 3D printing process. There are two containers – the feed material chamber remains full of powder; the build chamber is empty at the beginning. Both have a moving base, which can travel in the Z direction, whereas the printer head can move in X and Y directions, like an ink jet printer. At the beginning of the process the empty container's base is at the top of that container. A feed roller is used to spread a thin layer of powder over that base. The printer head then sprays glue on the powder according to the cross-sectional profile of the model to build the first layer. Once a layer is made, the base of the build chamber is lowered and the base of the feed material chamber is raised slightly. The whole process is repeated to produce the full prototype model. Like the selective laser sintering method, this method doesn't need any extra support for the overhanging portion of parts because powder serves this purpose. Moreover, excess powder can be used again.

Laminated Object Manufacturing

In this process, the object is made of layers of papers or plastic sheet containing adhesive. The layers are added together by applying heat, as shown in figure 2.6. The excess portion of the sheet that does not form the cross-sectional layer of the model is burnt out by a laser. The sheet material is fed by two rollers one at each end of the table on which the forming of layers takes place. Heat is applied to add a layer. Once a layer is formed, the table is lowered slightly and more sheet material is fed to produce the next layer. This process continues until the whole model is developed. The laser head is able to move in XY planes freely.

Figure 2.6: Schematic view of laminated object manufacturing method



Film Transfer Imaging Technology

Film Transfer Imaging (FTI) technology is the most recent development in the field of rapid prototyping. It has the advantages of increased speed, higher quality, and efficiency. In this method, a layer is constructed by curing resin with an ultraviolet flash of the cross-sectional image. A build pad is used; it is lowered to a table containing a thin layer of resin. The resin is cured by the ultraviolet photoflash of the cross sectional image of the prototype. This process continues until the whole model is built. (Vflash Brochure, 2008)

Case Study

Rapid prototyping was used in a bicycle tyre manufacturing company in Calgary where the tyre company needed to produce a master pattern for a casting mould. Traditionally, the tyre manufacturing company made the rough pattern by a machining process and then finished it by hand. The process was lengthy, taking 6 to 8 weeks to produce a set of moulds due to the complex shape of the tyre tread (Yan and Gu,1996). It was suggested that, by using Solider 4600 of Cubital America Inc., a 15-inch thick master pattern consisting of 254 layers, having 150 µm layer thicknesses, could be made within 8 hours. Solider 4600 is a system that uses light-curable acrylate photopolymer and a photo-masking technique to produce patterns. To build a new air-breathing planner array fuel cell, a process called MEM was used, which took about 12-36 hours. After switching to rapid prototyping, it took roughly one hour to finish the task, much faster than even CNC machines, which took two hours (Chen et al., 2008). Rapid prototyping significantly reduces design to production lead time and material wastage in manufacturing high performance sportswear (Chowdhury et al., 2012). In assembly operation, the use of Rapid prototyped models develop better understanding of assembly sequence, assembly time and resource required than 3D digital model (Ahmad et al., 2015).

Experiment

The author conducted an experiment to make prototypes using rapid prototype technologies and a CNC machine. The goal was to compare the surface quality, cost of production, and time required to produce model using both technologies.

The techniques for rapid prototyping are fused deposition modelling and three-dimensional printing. A computer mouse was chosen as a prototype for the experiment. The mouse was designed using the CAD software SolidWorks. The material used for fused deposition modelling was plastic, for 3D printing starch powder, and for CNC machine wood. Dimension SST1200 was used for the fused deposition modelling technique. Zcorp 310 was used for 3D printing technique. The CNC machining technique used Denford router 2600.

Comparison

Table 1 compares the three methods of producing the model in terms of material requirements, time required. Figure 3 shows visually the surface finishing of all the models lined up. The evaluation of surface quality by visual and touch inspection is shown in Table 1. The Dimension SST1200 machine used 100 cc material including the support and the total cost of material is £25.00, whereas the Zcorp 310 machine used 46 cc material, which cost £5.98 and super glue cost £3.00 resulting in a total cost of £8.98. The CNC machine used 100 cc material and cost only £1.00.

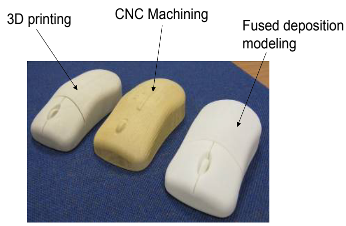
The total time taken for fused deposition modelling was 9 hours 20 minutes of which 4 hours to remove the support. 3D Printing required 1 hour 20 minutes to make the model and an additional half an hour to glue it. CNC machining was the cheapest and quickest process in this case. From visual and touch inspection of the surface quality, it produced a poorer quality surface than the other two techniques. For a large model this roughness of surface may be neglected; however, for small scale and precise models this roughness can change the shape of the object.

The model produced in fused deposition modelling technique had the best surface finishing and was strong enough to be used in a real system to some extent; however its cost and manufacturing time were the highest among the three options. Therefore, a trade-

Table 1: Comparison of cost, time required, material required and surface quality

Process	Total Cost (£)	Time Required (hour)	Material Required (CC)	Surface Quality
Fused deposition modeling (Dimension SST1200)	25	9.33	100	Smooth
3D Printing (ZCorp 310)	8.98	1.83	46	Average
CNC Machining	1	0.5	100	Rough

Figure 3: The finished models made by above mentioned processes.



off between cost and quality arises. For large models, as surface finishing is a minor concern, CNC machining is appropriate because it is cheaper and less time consuming while, for small and precise models with intricate shapes, fused deposition modelling is the best option because for small scale models surface quality is more important than cost.

Conclusion

Rapid prototyping is a powerful tool for making prototypes; it can sometimes also be used for mass production. The different types of rapid prototyping techniques discussed in this paper need to be developed further in terms of producing high quality, low cost product at a faster production rate. From this study, it can be concluded that the CNC machining is the cheapest and quickest process to produce prototype; however, the surface quality is far better in rapid prototyping.

References

Ahmad, A., Darmoul, S., Ameen, W., Abidi, M. H. and Al-Ahmari, A. M. (2015) "*Rapid Prototyping for Assembly Training and Validation*", *IFAC-Papers On Line*. Elsevier Ltd., Volume 48, Issue 3, Pages 412– 417. doi: 10.1016/j.ifacol.2015.06.116.

Chen, C. Y., et al. (2008) *"Planar array stack design aided by rapid prototyping in development of air-breathing PEMFC". Journal of Power Sources*, Volume 179, Issue 1, Pages 147-154.

Chowdhury, H., Alam, F., Mainwaring, D., Beneyto-Ferre, J. and Tate, M. (2012) *"Rapid prototyping of high performance sportswear", Procedia Engineering*, Volume 34, pp. 38–43. doi: 10.1016/j.proeng.2012.04.008.

Dickens, P. (2001) Rapid Manufacturing. In McDonald, J. A., Ryall, C. J. and Wimpenny, D. I. (eds). "*Rapid Prototyping Casebook*". Trowbridge, Wiltshire: Professional Engineering Publishing Limited. Pages 239-247.

Kalpakjian, S. and Schmid, S. R. (2006) "*Manufacturing Engineering and Technology*". Fifth Edition. United States of America: Prentice Hall.

Kochan, A. (2000) *Rapid prototyping gains Speed, volume and precision. Assembly Automation",* Volume 20, Issue 4, Pages 295-299.

Muller, A. and Karevska, S. (2016) "*How will 3D printing make your company the strongest link in the value chain?"* Available at: http://www.ey.com/Publication/vwLUAssets/ey-global-3d-printing-report-2016-full-report/$FILE/ey-global-3d-printing-report-2016-full-report.pdf (Accessed on 17/10/2017).

Upcraft,S. and Fletcher, R. (2003) "*The rapid prototyping technologies. Assembly Automation",* Volume 23, Issue 4, Pages 318-330.

Vflash Brochure (2008). Available at: http://www.modelin3d.com/V-Flash_Brochure_NAV2.pdf (Accessed on 22/02/2008).

Yan, X. and Gu, P. (1996) *A review of rapid prototyping technologies and systems. Computer Aided Design",* Volume 28, Issue 4, Pages 307-318.

Zorriassatine, F., et al. (2003) *A survey of virtual prototyping techniques for mechanical product development. Engineering Manufacture"*, Volume 217, (Part B) Pages 513-530.