International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 12, Issue 11(November 2016), PP.24-33

Exploring the Benefits of Rapid Prototyping for Effective and Speedy Mass Production

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Abstract:-The changing trends in appearance and style have led to frequent introduction of consumer and engineering products unto the market. The need to reduce cycle time from the conception of a product to its mass production has become evident. This paper introduces the concept of using technologies collectively known as Rapid Prototyping (RP) for the manufacture of end use products. The paper described the process of rapid prototyping using stereolithography. A 3D printer used as one method of RP, was equally described and sample designed product like car model and scissors jack were used for illustration. This study ends by providing possible benefits of using RP which are mainly saving time and cost.

Keywords:-Stereolithography, 3D printer, rapid prototyping, Scissor jack, CAD model

I. INTRODUCTION

Rapid Advanced Processor In Development (RAPID) is a prototyping technology that accelerates the development of state-of-the-art processor systems, particularly those involving custom boards and firmware [1]. Rapid Prototyping refers to a group of commercially available processes which are used to create solid 3D parts from computer aided design (CAD), from this point onwards these processes will be referred to as layer manufacturing techniques (LMTs). Rapid Manufacturing uses layer manufacturing techniques (LMTs) for the direct manufacture of solid 3D products to be used by the clienteither as parts of assemblies or as stand-alone products. Rapid prototyping is different from traditional fabrication in that it is only possible through the use of computers, both to generate the 3D CAD model data, as well as to control the mechanical systems of the machines that build the parts [2].

Virtually all RP processes are “additive”. Parts are built up by adding, depositing, or solidifying one or more materials in a horizontal layer-wise process. The part is built up layer by layer until done. This is similar to the result one would get if one made a topographical map of the object, with the contour lines representing the layer. According to [3], Rapid prototyping is new technologies to cut time to market of a product, by as much as 75% or more in some cases.

[4] explained that most commercially available rapid prototyping use one of the following six techniques: Stereolithography, Laminated Object Manufacturing, Selective Laser Sintering, Fused Deposition Modelling, Solid Ground Curing and 3-D Ink-Jet Printing. [5] also make use of another technique known as shape deposition manufacturing.

Stereolithography also called SLA or SL, is a type of standardized computer exchange file which contains a 3D model. The representation of the surface(s) of the object(s) in the file is in the form of one or more polygon meshes. The polygon meshes in an STL file are entirely composed of triangular faces, edges and vertices [2], [6]. On the other hand, the Selective Laser Sintering was developed by Carl Deckard for his master’s thesis at the University of Texas and was patented in 1989. The technique uses a laser beam to selectively fuse powdered materials, such as nylon, elastomeric, and metal, into a solid object [4].

In the recent past many sophisticated engineering product were designed using RP. Boeing’s Rocket dyne propulsion and power section has used Selective Laser Sintering (SLS) to manufacture low volumes of parts purposely for the space laboratory and space shuttles [7]. The feasibility of selective laser sintering (SLS) and hot isostatic pressing (HIP) has been successfully demonstrated for a simple cylindrical shape made of Inconel 625 super-alloy [8]. RP technologies are successfully used by various industries like aerospace, automotive, jewelry, coin making, tableware, saddletrees, biomedical etc. It is used to fabricate concept models, functional models, patterns for investment and vacuum casting, medical models and models for engineering analysis [9].

Another RP techniques intensively used is the Fused Deposition Modelling (FDM). [10] asserted that there were diverse controls and material selection parameters that affected prototype models built using the Fused Deposition Modeling (FDM) process. The FDM process allows user to control the envelope temperature, the liquefier temperature, the modeling speeds and the materials to name just a few variables. Each of these variables can alter the resulting model. The appropriate setting of these parameters by the operator is essential to quality model production.

The idea of using Rapid Prototyping machines for the manufacture of products in high or medium volumes initially seems unrealistic as cycle times, materials costs and capital equipment for processes such as injection molding are generally far lower than those for Rapid Prototyping [7].

This paper therefore explores the benefits of using RP to improve the quality of shapes of engineering products, to increase their massive production and reduce manufacturing time and at large contribute to economic development.

II. OVERVIEW AND TYPES OF RAPID PROTOTYPING

This section presents the overview of rapid prototyping and explores various types of rapid prototyping.

A. Overview of Rapid Prototyping

Rapid prototyping methodology’s key features include reusing previously proven designs, a highly productive design environment, and an inexpensive prototyping test bed. The design of the test bed allows the infusion of new technologies, while maintaining a stable user interface. In addition, an efficient, integrated development environment that includes reference designs has been created to streamline the prototyping process. RAPID offers a field-programmable gate array (FPGA) common design environment, referred to as a container that has open and stable interfaces. This container framework provides an enhanced controllability and observability of new designs, resulting in a significant productivity improvement in FPGA development, verification, and integration.

As mentioned earlier, the re-configurability of field-programmable gate arrays motivates their use in many areas that require application-specific performance. This field-programmable gate array benefit will only be fully realized if a design environment that facilitates application development and debugging is available. Unfortunately, current field-programmable gate array design tools require the designer to write code to perform almost any debugging activities, such as setting and examining the internal values of a field-programmable gate array. This situation is reminiscent of the early days of computing when computers did not have an operating system. In addition, lacking a low-overhead, standardized control infrastructure for the field-programmable gate array is a huge barrier for other subsystems to interface with the field-programmable gate array.

In many situations, especially those involving cutting-edge technology, new designs have unanticipated problems that are difficult to predict by modeling or simulation. When the performance of a new device is uncertain, an early development of a prototype can be useful for testing key features of the design, exploring design alternatives, testing theories, and confirming performance prior to starting production. Prototyping is typically an iterative process, in which a series of products will be designed, constructed, and tested to progressively refine the final design. It is thus essential to minimize the latency of each prototyping cycle so that projects adhere to the original design schedules.

A typical prototyping flow of a high-performance embedded signal processor begins with a design phase in which the desired system capability is analyzed to determine hardware and software requirements. Next, in the implementation phase, the signal processing software and appropriate computational hardware are developed. In the conventional development flow, design steps are executed sequentially, and the entire process takes between 15 to 24 months. In the new RAPID design flow, a surrogate system is used for software and firmware development while the processor boards are being customized and fabricated for the objective system. The open-interface container allows the development of firmware. The next paragraphs present some advantages and disadvantages of RP.

- **Advantages**
  - It is widely known for its ability to fabricate 3-Dimensional geometries with complete shapes.
  - Having the ability to shorten the cycle of product development whiles improving the process of design by facilitating quick and reliable feedback to the designer; hence helping the organisation to forge ahead a market which is rapidly changing.
  - Reverse engineering in the concurrent engineering application with 3D digitisation integration and rapid prototyping shortens markedly cycle time of product development.
  - CAD software can be used to modify the 3D CAD model and a prototype manufactured with Rapid prototyping saving lots of money and time.

- **Disadvantages**
  - This method is not good for large sized purposes mainly restricted by the size of the tray in the printer.
  - Because of the desire to get to the market quick, so many developmental steps are omitted to obtain a working model that is cheap.

- Several bottlenecks are under- estimated which ultimately results in cyclical corrections and alterations. And that process goes un- ending.
- That RP reduces costs is debatable since several details on which the determination is made are grossly over- looked.
- While helping the organisation to test components before production, the accuracy is only within 0.1mm, which is a deviation and also the difficulty with parts that can be created with fine patterns or thin walls.
- Acquisition of the printer is a cost which comes around US$ 25,000.00 even when out-sourced, can be substantial and adds up the cost of production

Several materials have been developed but there is still the need to research into the newer materials and processes. Even though SLS is relatively new it must be noted, the continued development of the technology and its understanding for the various processes is still required to carry forward the technique and move forward. The addition of desirable effects can be obtained from the addition of polymers to clay will produce desirable mechanical properties of parts. The knowledge of existing materials and their complexity when being processed by laser will facilitate obtaining functional requirements of parts in the present and future applications. (Jijotiya, 2013)

The use of RP in the fields of medical science is commendable; from medical simulation, planning, production of models and training. With RP, surgeons can now break- through with findings that generations before them could only imagine. This calls for collaboration among engineers and surgeons in research that will facilitate the issues of cost, speed, and accuracy with which findings can be made[13].

B. Direct Metal Laser Sintering (DMLS)

The use of heat generated from laser is employed to sinter metal powders in thin layers in the creation of finished components. Suitable materials include cobalt chromium, stainless steel, titanium and steel. The process has advantages in the production of metal parts of net shapes. Conventional production of net shapes results in complex parts that are very accurate. Known disadvantage is that, available materials are limited in the production of surfaces that are rough. Polishing of the surfaces is difficult unless subsequent machining is performed.

This manufacturing process is additive (or 3- Dimensional Printing) technology for the production of parts and metal prototypes taking few hours. DMLS is compatible with a variety of materials (metals and their alloys) in the creation of durable and strong parts using 3-D CAD data not using tooling. Parts from this technology have design versatility of layer additive manufacturing whilst still maintaining the mechanical properties and aesthetics of the materials.DMLS technology is excellent and accurate at re- producing all the fine details which is ideal for aerospace components, high temperature applications, dental and custom medical parts, prototypes that are smaller and tough functional prototypes. The schematic is as shown in Figure 1 below.

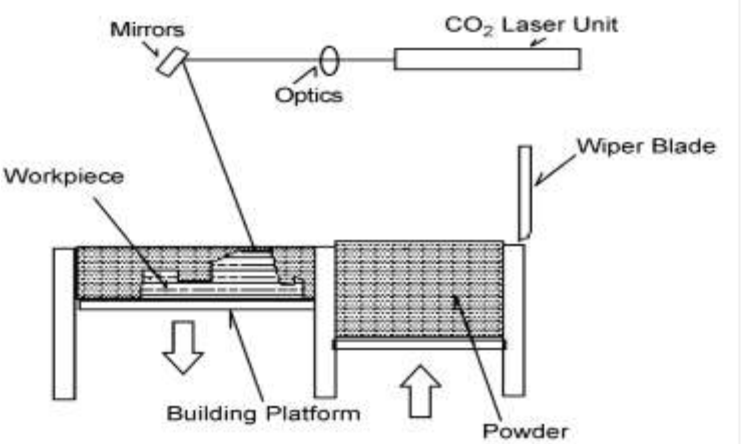


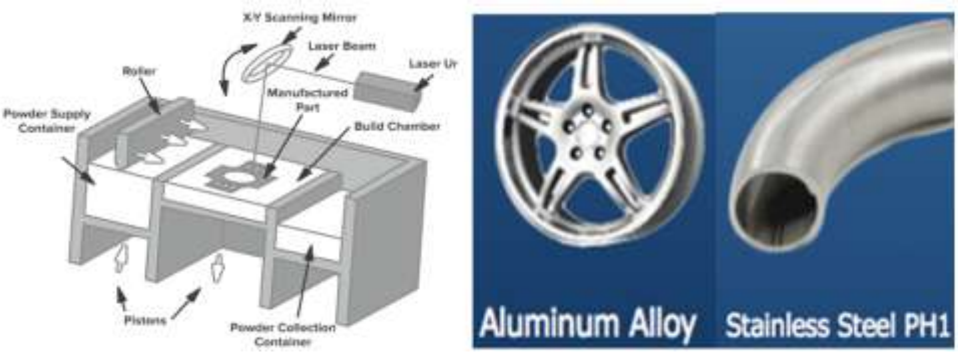
Fig. 1:A schematic of the DMLS process

The arrival of the first DMLS machine posed a threat to traditional machining since filling the machine with metal powder, followed by loading a CAD file and after a while, a new finished part is ejected. This technology has very little waste, no cutting tools to sharpen and set up are simple but DMLS turned out to complement traditional machining. Its metal parts directly from CAD models are fully dense with surface finish and accuracy allowing parts to go directly into service. Complex parts highly impossible to machine can be fairly handled by DMLS.

After loading the 3- D CAD model of the part to proto-lab, the following steps will produce the part.

1. The CAD model is digitally sliced into paper- thin layers, with the needed structures of support designed in to aid the laser sintering process. Uploading of files to DMLS machine then takes place.
2. Stainless steel, cobalt chrome, titanium, Inconel or aluminium is filled into the powder bed whilst distributed across the built platform is a thin layer of the selected material.
3. The build begins with the high powered laser commencing, drawing the lower level of the first batch, around this time, any support structures for the build process are also made.
4. Rubber wiper scrapes a layer of thin metal powder across the parts as the laser process is repeated.
5. On completion, the partly finished component is taken out from the build chamber and supports are detached, after which the component is finished according to clients' specification.

The five steps described above are shown in the Figure 2 below with typical products of the process from powder supply to the build chamber also shown. Typical items (automobile alloy parts) capable of being produced using the process is shown in Figure 2 (b) below.



(a) DMLS printer **(b)** Typical parts produced from this process

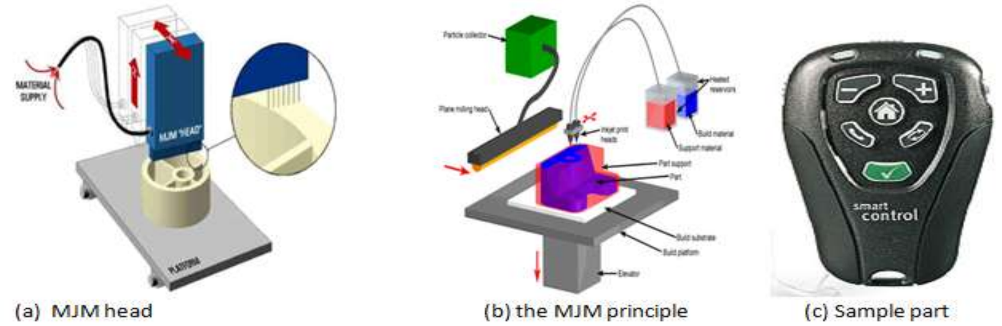
Fig. 2: Direct Metal Laser Sintering Printer and Products

Source: [11]

DMLS provides high resolution build at thicknesses of about 0.02mm and part tolerances in the region of ± 0.076 mm and surface finishes like that of sand casting. DMLS is preferred because a variety of alloys are suitable and enjoys patronage in the medical, consumer and aerospace industries.

C. Multi-Jet Modelling (MJM)

The Multi- Jet Modelling uses jet of lines of piezo- metric ink to deposit droplets of molten plastics layer- by- layer as shown in Figure 3. It is designed with concept models as a printer in 3D network and uses paraffin- based thermo- polymer. Part sizes are in the order of 250mm x 190mm x 200mm and the accuracy of the 400x 300 dpi resolution in the plane x-y.The facility costs approximately US$ 50,000 with the machine layout in (a), principle in (b) and sample model (c) shown in the Figure 3 below.



(a) MJM head (b) the MJM principle (c) Sample part

Fig. 3: the Multi- Jet Modelling

Source: [12]

D. Laminated Object Manufacturing (LOM)

The Laminated Object Manufacturing works on the principle that, it cuts and laminates foils normally self-adhesive with characteristics often not complex.Paper is mostly used in this type of system even though ceramics, plastics and metals may be applied. Part sizes are within $813 \times 559 \times 508 (mm)$ with ± 0.25accuracy attainable for a cost range of USD 55,000 – USD 278,000.

Increasingly; cost, time to market and product quality are becoming determining factors in the success of a product. Prototypes play a major factor in the product development cycle hence how soon it takes to develop a prototype directly affects time to test and launch. There are some markets where customer- tailored products are demanded so that the time and cost of tools and moulds are considerable. It is the desire to overcome the fore- mentioned problems that the Laminated Object Modelling was developed.

In this method, the component is cut in thin slices from the blank using CO$_2$havinglaser mounted on a two- dimensional plotter. Most commonly, sheets of paper are stacked automatically on each other with the help of adhesive, while support is provided by sheet outside the model as shown in figure 4 below. Intersecting lines are marked on unwanted areas forming cubes that are later broken off on the completion of the model.

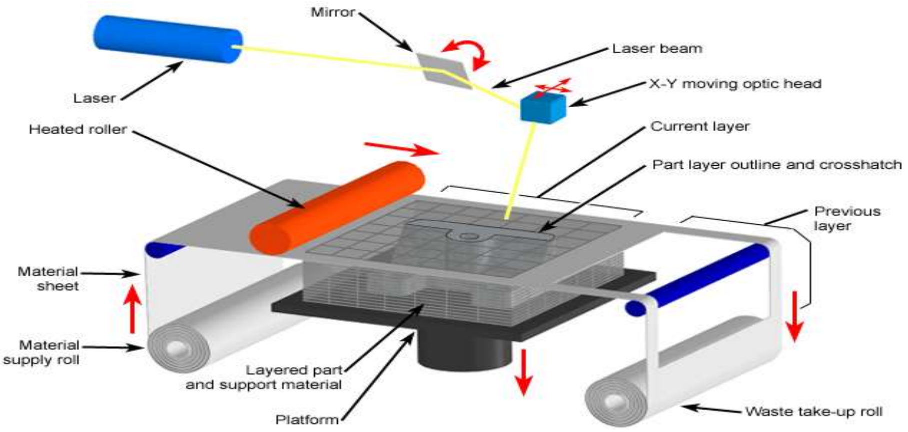


Fig. 4: Schematic of laminated object manufacturing
Source: [14]

- **Advantages of the Laminated Object Modelling**
  - Support structures for components are not needed.
  - Whereas other methods process the whole part, this method processes only the circumference.
  - High manufacturing speeds are possible
- **Disadvantages of the Laminated Object Modelling**
  - There is difficulty of producing good bonds between the thin layers
  - Surface finish is poor
  - It is difficult to produce hollow parts

This process has also been used to manufacture alumina bio- medical filters and silicon nitride turbine blades, which confirm the process's suitability in applications where costs are prohibitive because of small order sizes. It is also used for bone bio- structures from phosphate- based ceramics, zirconia and alumina for research purposes. The Figure 5 below shows the principle, during the process, when the supports are being removed and a model car.

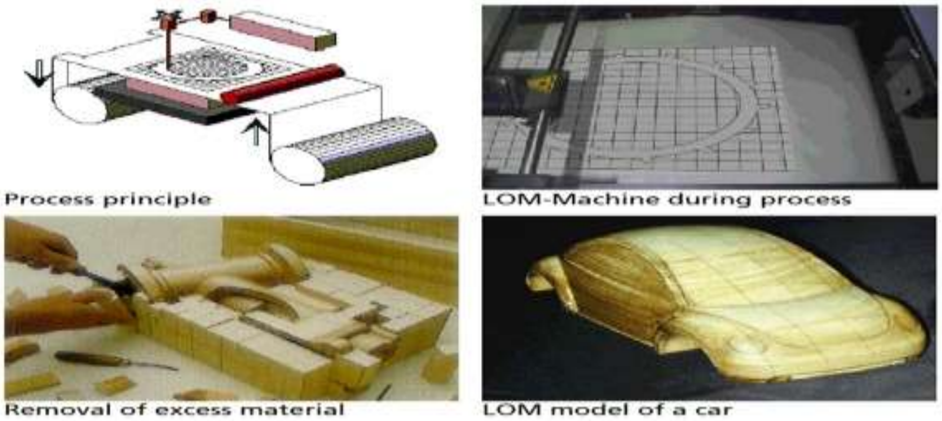
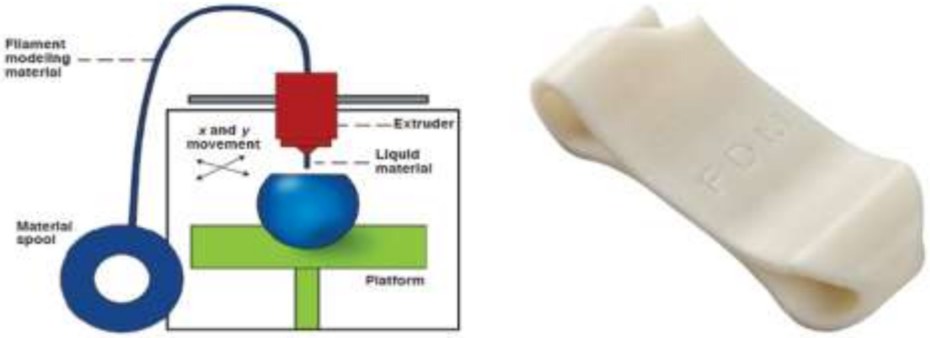

Process principle
LOM-Machine during process
Removal of excess material
LOM model of a car

Fig. 5: Diagram of Laminated Object Manufacturing

E. Fused Deposition Modelling (FDM)

This is another rapid prototyping process which uses production grade thermoplastics ABS, PLA, Nylon, etc.) for the benefit of both the end- user and the prototypes. The process of 3D is preceded by CAD data previously prepared by slicing the model and making thin layers to be used in guiding the machine after. Below in figure 6 (a) is the principle and in (b) is a typical part produced.



(a) The FDM principle(b) typical part

Fig. 6: The fused deposition process

Source: [15]

Here, the extrusion of the material occurs through the nozzle tracing the parts outline layer after layer. The material is supplied in the form of a filament however, other types use plastic pellets being fed from a hopper. The nozzle contains an electric resistance element that maintains a temperature above the melting point of the plastic to enable it to flow freely to form the layer.

It immediately hardens after and bonds to the layer beneath it. The platform is lowered and another layer is deposited. The vertical dimensional accuracy and the layer thickness are determined by the diameter of the die which is normally in the range of 0.1 mm to 0.35 mm depending on the software, the CAD model and the machine. A resolution of 0.0254 mm is achieved in the X-Y plane while materials range from polyamide, polyethylene, investment wax, and polypropylene. Built sizes range from 100 x100 x100 (mm) to 250 x 300 x 250 (mm).

F. Selective Laser Sintering (SLS)

Another advanced technology similar in concept to the Stereo lithography (SLA) in the application of the additive manufacturing method is the Selective Laser Sintering (SLS) where the use of high laser power source is employed to make directly 3- D components from powdered material. The layer- by- layer cross-section of the thermoplastic powder is fused by the CO_2 laser beam which spreads over the surface sintering areas specifically instructed by the CAD model. After the completion of the first layer, the bed is lowered slightly and fresh part material is distributed as shown in figure 7.

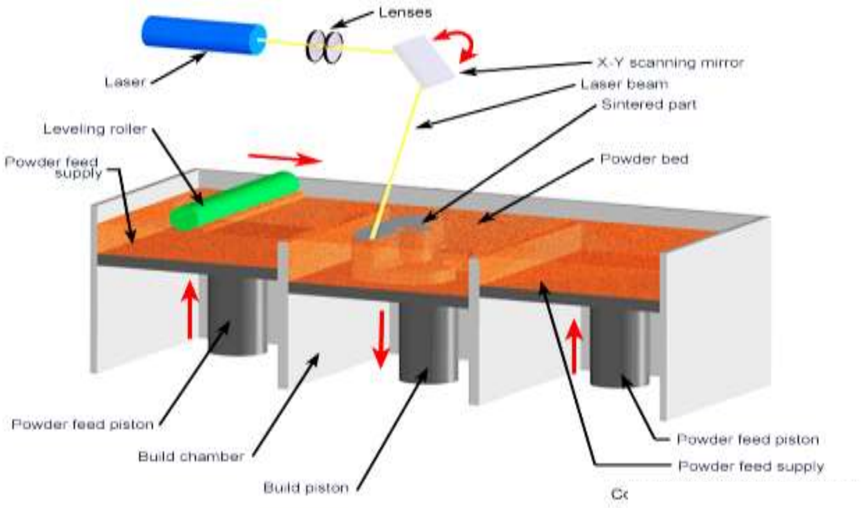


Fig. 7: Schematic of selective laser sintering

Source: [16]

Selected areas of the layer are scanned resulting in bonding to the layer done previously. Support is provided for by un-sintered material but which is cleaned and recycled on completion of the build. (Deckard, 1986; Kruth et. al., 2003; Kumar, 2003; Pham et. al., 1999).

Kruth et. al., 2003 assert that, despite polymers being used earlier on and continue to be preferred for SLS, metals, ceramics and a variety of other materials are getting attention due to their relatively excellent sintering laser power, high accuracy low processing temperature. Much of polymers processed using SLS are of the thermoplastic type with saving in cost occurring as a result of material recycling (Gibson and Shi, 1997). Surface finish obtainable from this process is average with minimum layer thicknesses in the range of 0.10 mm, suitable for functional and form/ fit testing and applicable to high temperature applications.

III. PRODUCTION OF SCISSOR JACK USING RPPROCESS

Figure 8 exhibits a scissor jack drawn in Solid Work. The scissor jack is used in raising substances to obtain alignment, lifting cars (automobiles) during tyre change and other minor work. Scissor jack has different versions and designs on the market, with a high turnover as a result of the ease of acquisition. Consequently, new designs or change in aesthetic characteristics captures the attention of car owners. It is believed that, with haste in developing and modelling such an item, massive production can be attained to meet the consumer's request. The prototype will assist procurement and sales personnel to examine and make criticisms before the final product is finally launched onto the market. It must be noted that, the key characteristics of successful products are conformance, speed of delivery, brand name, price, functional performance, reliability and after sales service. One important stage in the RP process is the selection of appropriate machine to perform the required task.

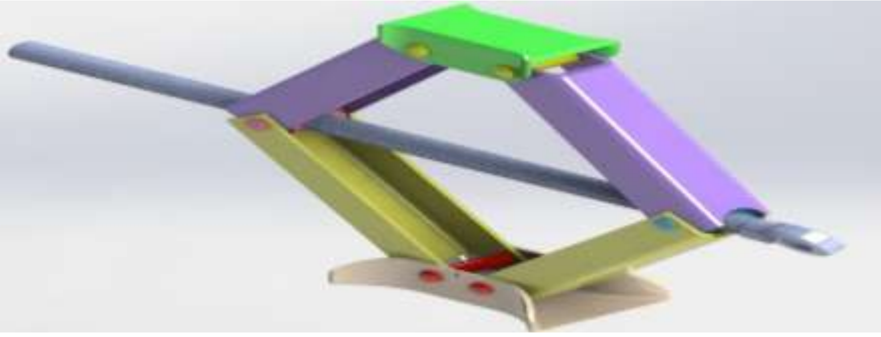


Fig. 8:A Scissor Jack

The decision to acquire suitable equipment for any process depends on many complexities among which consideration is given to the present and future use of the machine.Several quantitative and qualitative criteria should be accounted for by the decision maker some of which are complexity, flexibility, user friendliness, cost, environmental considerations as well as technical capabilities. The type of machine to be used in modelling the prototype will depend on system compatibility, cost involved and the desired accuracy. Also, accessibility to Rapid Prototyping **(**RP) vendors including internet sites, advisory boards, professional organizations and conference workshops may be considered. Brown, 2002

With consideration to all the above factors, if the selected machine is Stereolithography (SL) type meaning the part is produced using a layer-by-layer approach; then the obvious benefits will include good accuracy and ease of manufacturing complex structures and undercuts which may be produced of varying qualities from photopolymer.

a) Closed Objet 3D printer

b) Open Objet printer showing model under Construction

Fig. 9: Objet 3D Printer

Source:[17]

With the Objet 3D printer, accuracy and versatility are combined with its small footprint. It has a standard that is highest in resolution providing unique capabilities in seven different kinds of materials. It also has the ability to produce temperature-resistant material, polypropylene and transparent printing with reliability and ease of operation. Figure 9 (a) above shows the printer and 9 (b) shows the open printer to exhibit the model under construction.Four commonly used materials for Rapid Prototyping (RP) process are

(i) machine-able wax
(ii) investment casting wax
(iii) P200, polyolefin type and
(iv) P300, polyamide type.

Properties generally desired of Rapid Prototyping (RP) materials are tensile strength, flexural strength, elongation and hardness [10].

Stereolithographyis a form of 3-D printingtechnology used for creating models, prototypes, patterns, and production parts in a layer by layer fashion using photo- polymerization, a process by which light causes chains of molecules to link together, forming polymers as discussed earlier. It is made up of four different stages depicted in Figure 10 below.

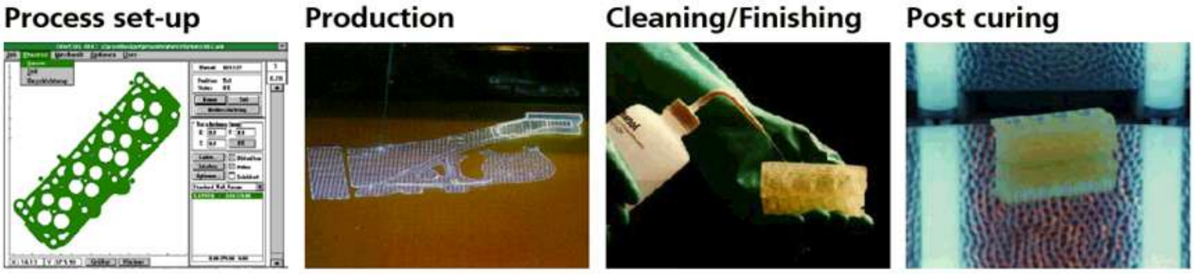


Fig. 10: the step-by-step process of SL technology

- ***First Stage: Process Set-up***
  The setting up and transfer of data is done at the beginning of the building process where also, a multiplicity of logically connected actions or roles (such as production, sales or planning) are executed together for an outcome well defined.
- ***Second Stage: Production***
  The build-up of geometry by layer occurs at the production stage, involving methods and processes that transform the raw materials into semi- finished/finished goods. In the end, the process creates the output from the resources having enhanced value.
- ***Third Stage: Cleaning/Finishing***
  Removal of excess resin is undertaken after the completion of the build-up component and it is integral to most applicationsand important because of the variety of impurities found during processing. Equipment for cleaning have different targets such as buffing, cutting, grinding, sealing, vibratory cleaning, blast cleaning, abrasion and much more. The type of cleaning may also be determined by shape, weight, size and production rate of the formed part.
- ***Fourth Stage: Post Curing***
  Curing under ultra violet light is performed so that physical properties are optimised. It may occur in the form of polymerization or evaporation taking place but resulting in a tougher, harder and more stable bond.

Furthermore, the detailed operation of the SL technology is shown in Figure 11 below where light is transmitted from the laser, through the modulator and expansion optics through the scanner to the worktable where the layer-by-layer building occurs. The table moves in x- and y- axis (horizontally) with the z- axis being the vertical height of the object.

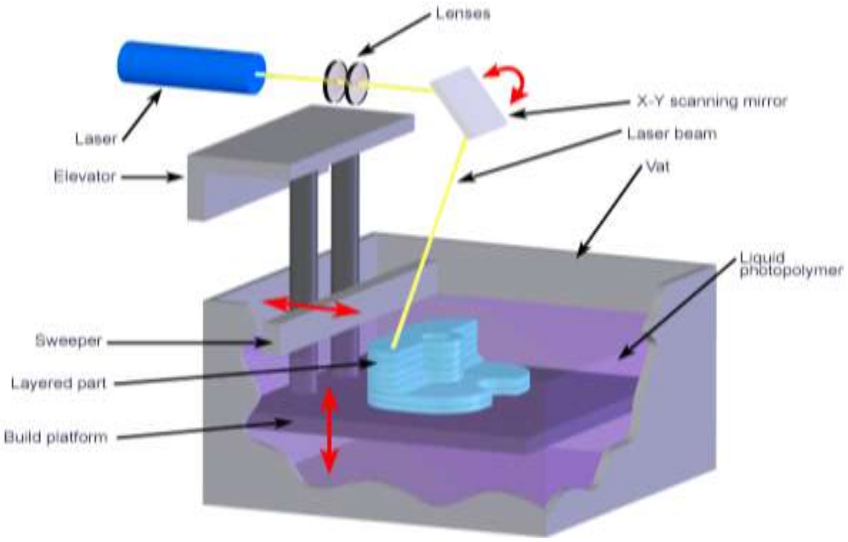


Fig. 11: Principle of operation of the SL process
Source: [18]

IV. FUTURE OF RAPID PROTOTYPING

Research & Development **(**R & D) has developed several materials and there are still continued efforts to obtain newer and better functional ones. The relatively new SL is outstanding for several processes and could even do better with further development. Improved properties of materials can be obtained by the blending of clay with polymer resulting in excellent mechanical qualities. An extensive knowledge of the materials will facilitate the requirement for functional parts for current and later applications [13]. Rapid Prototyping (RP) has several uses in medicine including heart-warming as simulations, resource planning, manufacture of models and training. Surgeons are now able to breakthrough with discoveries which their forebears only imagined [13].

The development and application of the technique of Rapid Prototyping (RP) industry has yielded double benefits: the provision of timely information that will help in the improvement of the process of design; the speedy production of tools and products. In the same regard, RP has helped to achieve a reduction in the time to market and also improvement in product quality by using prototypes which reveal the actual geometric models for the effective derivation of customer satisfaction, improvement in communication and the detection of early snags [6].

V. CONCLUSIONS

This paper explores the benefits of using rapid prototyping especially with the stereolithographic technique to design modern and accurate shapes. Rapid Prototyping (RP) procedure using 3D printers proved to be faster and cheaper. This paper proved that a great benefit of using Rapid Prototyping (RP) process is that it will enable customers examine their prototypes before the real functional components are produced in large quantities. Other benefits include the rapidity of product to reach market. On the other hand, some challenges faced by RP are the size of the model which is mainly limited by the size of the printer tray. Although poor surface finish, limited strength and accuracy are the limitations of RP models, it can deposit a part of any degree of complexity theoretically. This paper has equally emphasized the intensive use of RP technique in medicine and recommended other fields of engineering and sciences to adopt the technique for improved service delivery. In a nutshell, CAD/ SolidWorks application in the modification and manufacture of consumer products using Rapid Prototyping (RP) will save time and money.Cheaper machines and materials would help to reduce the costs of Rapid Manufacturing thus making their use more financially viable.

ACKNOWLEDGMENT

We deeply appreciate the enormous assistance that was received from Dr. Dani Harmanto (B.Eng. Program Leader) and Dr. John R. Begg both of the University of Derby, U.K. We also acknowledge the contribution and remarkable support of Mr. Stephen Agyemang, Former Head of Mechanical Engineering Department, Accra Technical University, Accra, Ghana.

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