iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 5 **Issue:** VII **Month of publication:** July 2017

**DOI:**

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887*
*Volume 5 Issue VII, July 2017- Available at www.ijraset.com*

# Design and Fabrication of Industrial Components using 3D Printing

Vijayakumar M. D[1], Anshumaan Krishnan Ayyangar[2]
[1]*Head of the Department, Dept. of Mechanical Engineering, Chennai Institute of Technology, Chennai, TN, India*
[2]*Final Year Student, Dept. of Mechanical Engineering, Chennai Institute of Technology, Chennai, TN, India*

***Abstract: In the product design and development process, prototyping or model making is one of the important steps to finalize a product, which helps in realization of a conceptualized design. 3D Printing, as a prototyping method, has been used widely since the 2000s, once it became popular as an additive manufacturing method. This paper aims at revolutionizing the aforesaid method further, to 3D print final components, instead of just prototypes, in all areas applicable, using some industrial components as samples. This paper will provide further scope of research into the possibilities of replacing metallic components with non-metallic ones, due to the rising costs and dwindling resources, so as to sustain the same utility of product without any compensation on durability and quality.***
***Keywords: additive manufacturing; design; fabrication; 3D Printing; industrial components; FDM; ABS; ABS-FR; modeling; finishing; rapid prototyping.***

## I. INTRODUCTION

Manufacturing processes are significant in all areas of our lives, so much that we often do not realize or think about its value. From the cars we drive, the containers our food comes in, the televisions, computers and various other devices we use, power tools, heaters, air-conditioners, the pipes that deliver our water, and the list goes on to include just about everything that defines our modern society. These things are all manufactured or built from manufactured components. Manufacturing equipment itself must also be manufactured. The process used is determined by a variety of factors. The rudimentary idea of manufacturing or production is to create (or produce) something that has a useful form. This form is most likely predetermined and calculated, with a certain physical geometry. Usually this geometry has certain tolerances that it must meet in order to be considered acceptable. A tolerance outlines the geometric accuracy that must be achieved in the manufacturing process. The "tightness" of the tolerances, or in other words the allowed variance between the manufactured product and the ideal product, is a function of the particular application of the product. Manufacturing is the production of merchandise for use or sale using labour and machines, tools, chemical and biological processing, or by formulation. The term may refer to a range of human activities, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users and consumers. Manufacturing takes turns under all types of economic systems. In a free-market economy, manufacturing is usually directed toward the mass production of products for sale to consumers at a profit. In a collectivist economy, manufacturing is more frequently directed by the state to supply a centrally planned economy. In mixed market economies, manufacturing occurs under some degree of government regulation. Modern manufacturing includes all intermediate processes required for the production and integration of a product's components. Some industries, such as semiconductor and steel manufacturers use the term fabrication instead.

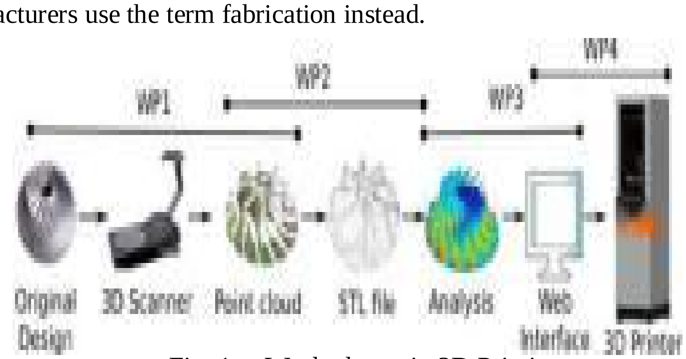


Fig. 1. Work phases in 3D Printing.

## II. MANUFACTURING METHODS

### *A. Subtractive Manufacturing*

Subtractive Manufacturing is a process by which 3D objects are constructed by successively cutting material away from a solid block of material. Subtractive manufacturing can be done by manually cutting the material but is most typically done with a CNC Machine. Advanced CNC machines utilize multiple tools and cut around at least three (x, y, and z) axes such that they minimize the requirement for designers to flip the block. One of the principal advantages to subtractive manufacturing is the ability to machine an extremely thin piece of plastic into a living hinge. This kind of process is simply not yet possible in a 3D printer. For those prototypes that require living hinge components it is useful to produce certain parts using additive manufacturing while using the CNC machine for specialty components like a living hinge.

### *B. Additive Manufacturing*

Additive Manufacturing refers to various processes used to create a three-dimensional object. It is a term to describe set of technologies that synthesize 3D objects by adding layer-upon-layer of a certain material. Materials can vary from technology to technology, or application wise. The term Additive Manufacturing includes technologies like Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), Layered Manufacturing and 3D Printing. There are some common features for all Addictive Manufacturing, such as usage of computer together with special 3D modeling software. First thing to start this process is to create CAD sketch. Then AM device reads data from CAD file and builds a structure layer by layer from printing material, which can be plastic, liquid, powder filaments or even sheet of paper.

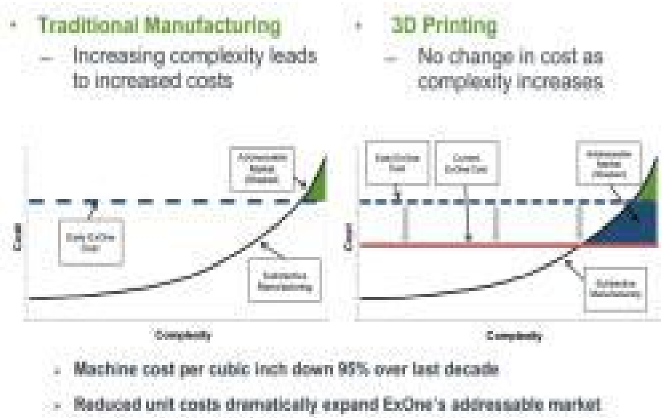


Fig. 2. Traditional Manufacturing vs. 3D Printing.

## III. 3D PRINTING

### *A. Principle of 3D Printing*

In 3D printing, successive layers of material are formed under computerized control to create an object. These objects can be of almost any shape or geometry, and are produced from a 3D model or other electronic data sources.

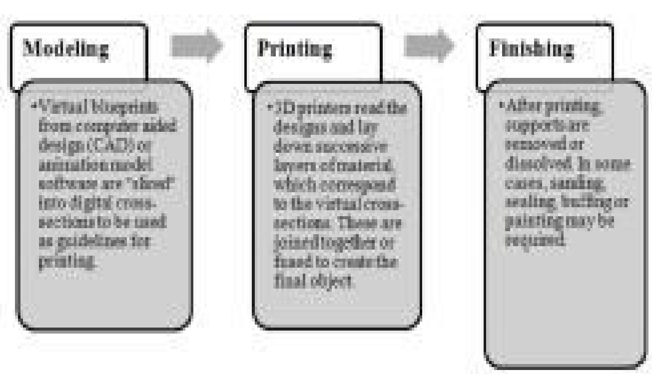


Fig. 3. Process flow.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887*
*Volume 5 Issue VII, July 2017- Available at www.ijraset.com*

*B. Types of 3D Printing*

There are different 3D printing methods that were developed to build 3D structures and objects. Some of them are very popular nowadays; others have been dominated by competitors.

The various types of 3D Printing are:

*1)* Stereolithography (SLA)
*2)* Digital Light Processing (DLP) Selective Laser Sintering (SLS) Selective Laser Melting (SLM)
*3)* Electronic Beam Melting (EBM)
*4)* Laminated Object Manufacturing (LOM) Fused Deposition Modelling (FDM)

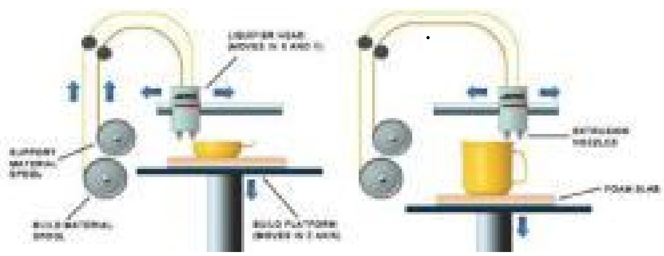

Fig. 4.FDM Process

*C. 3D Printer*

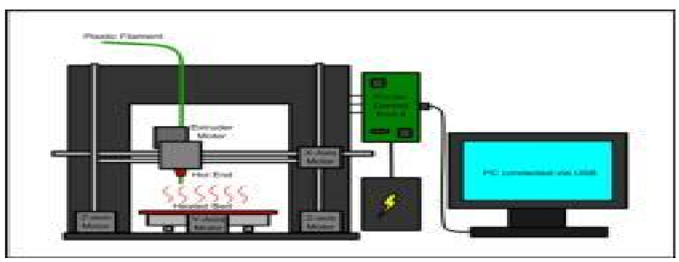

Fig. 5. 3D Printer setup (general).

A 3D printer is a type of industrial robot. It is a computer-aided manufacturing (CAM) device that creates three-dimensional objects. Like a traditional printer, a 3D printer receives digital data from a computer as input. However, instead of printing the output on paper, a 3D printer builds a three-dimensional model out of a custom material. 3D printers use a process called additive manufacturing to form (or "print") physical objects layer by layer until the model is complete. This is different from subtractive manufacturing, in which a machine reshapes or removes material from an existing mould. Since 3D printers create models from scratch, they are more efficient and produce minimal waste than subtractive manufacturing devices. The process of printing a 3D model varies based on the material used to create the object. For example, when making a plastic model, a 3D printer may heat and join the layers of plastic together using a process called fused deposition modelling (FDM). When creating a metallic object, a 3D printer may use a process called direct metal laser sintering (DMLS). This method forms thin layers of metal from metallic powder using a high powered laser. While 3D printing has been possible since the 1980s, it has been primarily used for large scale industrial purposes. However, in recent years, 3D printers have become much cheaper and are now available to the consumer market. As the technology becomes more widespread, 3D printers may become a likely means for people to create their own home products and replacement parts without major expenditure.

*D. Specifications of the 3D Printer used*

*1) Extruder:* MK10 Dual-Extruders
*2) Filament Size:* 1.75mm Dedicated
*3) Layer Capability:* 0.1mm - 0.5mm
*4) Build Envelope:* 225mm x 145mm x 150mm

5) *Build Surface:* Heated Build Plate with Glass Bed
6) *Filament Capabilities:* PLA, ABS, PVA, NinjaFlex, Nylon, LayWoo-D3, LayBrick, CopperFILL, BronzeFILL, MOLDLAY, Conductive, plus more.
7) *Compatible Software/Firmware:* ReplicatorG (Opensource), Sailfish (Opensource), Simplify 3D (Details).
8) *Frame Colour:* Black Steel Exoframe.

## IV. MATERIALS SELECTED

### *A. ABS*

Acrylonitrile Butadiene Styrene (ABS), with its chemical formula of $[(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z]$ is a common thermoplastic polymer. Its glass transition temperature is approximately 105°C (221 °F). ABS is amorphous and therefore has no true melting point. ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The end result is a long chain of polybutadiene criss-crossed with shorter chains of poly-styrene-co-acrylonitrile. The nitrile groups from neighbouring chains, being polar, attract each other and bind the chains together, making ABS stronger than purepolystyrene. Styrene gives the plastic a shiny and impervious surface. Polybutadiene, a rubbery substance, provides girth even at low temperatures. For the majority of applications, ABS can be used between −20 and 80°C (−4 and 176 °F) as its mechanical properties change with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix. The most crucial mechanical properties of ABS are impact resistance and toughness. A variety of modifications can be done to improve impact resistance, toughness, and heat resistance. The impact resistance can be increased by amplifying the proportions of polybutadiene in relation to styrene and also acrylonitrile, although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads. So, by changing the proportions of its components, ABS can be prepared in different grades. Two major categories could be ABS for extrusion and ABS for injection moulding, then high and medium impact resistance. Generally ABS would have useful characteristics within a temperature range from −20 to 80°C (−4 to 176 °F). The final properties will be influenced to some extent by the conditions under which the material is converted to the final product. For example, moulding at a high temperature improves the gloss and heat resistance of the product whereas the highest impact resistance and strength are obtained by moulding at low temperature. Fibres (usually glass fibres) and additives can be mixed in the resin pellets to make the final product strong and raise the operating range to as high as 80°C (176 °F). Pigments can also be added, as the raw material's original colour ranges from translucent ivory to white. The aging characteristics of the polymers are largely influenced by the polybutadiene presence, and it is usual to include antioxidants in the composition. Other factors include exposure to UV radiation, for which additives are also available to protect against. ABS polymers are resistant to aqueous acids, alkalis, concentrated hydrochloric and phosphoric acids, alcohols and animal, vegetable and mineral oils, but they are swollen by glacial acetic acid, carbon tetrachloride and aromatic hydrocarbons and are attacked by concentrated sulfuric and nitric acids. They are soluble in esters, ketones, ethylene dichloride and acetone. Even though ABS plastics are used largely for mechanical purposes, they also have electrical properties that are fairly constant over a wide range of frequencies. These properties are little affected by temperature and atmospheric humidity in the acceptable operating range of temperatures. ABS is flammable when exposed to high temperatures, such as a wood fire. It will melt, then boil, at which point the vapours burst into intense flames. Since pure ABS contains no halogens, its combustion does not typically produce any persistent organic pollutants, and the most toxic products of its pyrolysis (combustion) are carbon monoxide and hydrogen cyanide. ABS is also damaged by sunlight. This caused one of the most widespread and expensive automobile recalls in US history due to the degradation of the seatbelt release buttons earlier. ABS can be recycled, although it is not accepted by all recycling facilities.

*Typical Data Sheet*

PPR- ABS11

ABS General Purpose-Izod Black

| Test Description | Method | Properties English | Properties SI |
|---|---|---|---|
| Tensile Strength at Yield, psi (Mpa) | D-638 | 6,300 | 43.4 |
| Elongation at Break, % | D-638 | 35 | |
| Flexural Strength, psi (Mpa) | D-790 | 10,800 | 74.5 |
| Flexural Modulus (Tangent), psi (Mpa) | D-790 | 365,000 | 2,520 |
| Izod Impact (Notched), ft-lb/in (J/m) | D-256 | 4.0 | 216 |
| Melt Flow Rate, g/10 min. 230/3800 | D-1238 | 4.0 | |
| Specific Gravity | D-792 | 1.050 | |
| Heat Deflection Temperature | | | |
| At 264 psi, F (C) | D-648 | 185 | 85 |
| At 66 psi, F (C) | D-648 | 195 | 91 |
| Linear Mold Shrinkage | D-955 | 0.0060 | |

Fig. 6. ABS Post-Formation properties

### *B. ABS-FR*

Flame retardant ABS is a combination of ABS and PVC (polyvinyl chloride). This alloy was developed to comply with many rigid flammability standards established for computer housings, electronic data processing equipment, rapid transit interiors, and a broad range of other flame-retardant sensitive applications. This unique alloy of ABS-PVC produces a thermoformable sheet that is recognized under the component program of Underwriters Laboratories, Inc., with a classification of 94 VE1 at .062" thickness. ABS-FR maintains most of the physical and mechanical properties of ABS, and much like ABS, possesses excellent thermoforming capabilities. As explained in the previous section, flame retardant ABS may have some cons compared to general ABS except for flame retardance. However, a careful grade selection through the understanding of those features will guarantee the user's maximum satisfaction.

1) *Thermal Stability:* Since the self-extinguishing properties of flame retardant ABS may result from the thermal decomposition of flame retardants during burning, flame retardant ABS can have poor thermal stability in comparison with general ABS. In particular, since flame retardants can possibly decompose when moulded at temperature of 230$^{o}$C or above, moulding at lower temperatures than required with general ABS is recommended. Cheil Industries Inc. has developed the technology to produce Starex flame retardant ABS with excellent thermal stability and flame retardancy. Starex flame retardant ABS, especially VH-0853 and VH-0800, is useful for geometrically complex moulds.
2) *Weather Resistance:* Since ABS contains butadiene to enhance impact strength, it can be discoloured if exposed to sunlight for a long time. And this prevents its usefulness with such O.A. applicances as computer monitors, printers, and photocopying machine. As one of the leading companies in the production of ABS resin, Cheil has made the effort to solve these problems, and it has successfully produced a flame retardant ABS series with excellent weather resistance. Among the series, VH-0853, VE-0812, VE-0855 or VE- 0856 can be the best choice for applications demanding weather resistance.
3) *Blooming and Plating-Out:* During injection moulding, flame retardants can diffuse out to the surface to cause mould contamination. Since this phenomenon turns worse with darker colours, it is recommended not to use flame retardant ABS grade resins with dark colour shades. However, blooming is not observed while using all Starex flame retardant ABS grade except VH-0853. Starex flame retardant ABS grades with their excellent qualities allow for flexible product designs.
4) *Heat Resistance:* Heat resistance implies that the product is not prone to deformation while being exposed to a wide temperature range. The excellent heat resistance of Starex flame retardant ABS makes it possible to increase the reliability of injection moulded products. However care must be taken to select the proper grade of Starex flame retardant ABS for final use. For cost reduction and improved injection productivity, the VE-series can be the best choice as an engineering plastics substitute, while the VH-series is suitable when process ability is more important design factor than heat resistance.
5) *Flammability:* Generally, flammability can be rated according to UL-94 VB standards. Cheil produces various flame retardant ABS forms with varying flammability levels to meet the requirements of specific applications.
6) *Flame Retardants:* PBDE is one of the most popular compounds used as an additive to promote the flame retardance of plastics. There was a trend to restrict PBDE's use as a flame retardant compound due to the possibility that PBDE could induce toxic dioxin or difuran derivatives at an elevated temperature condition. Even though it has been speculated that PBDE is not so dangerous, most electric and electronic companies still avoid using PBDE as a flame retardant. Starex flame retardant ABS resins do not contain such controversial flame retardant compounds. Therefore, Starex flame retardant ABS can be used for exterior applications.

**Typical Data Sheet**

PPR-ABS[illegible]

ABS Plateable Grade Gray

| Test Description | Method | Properties English | Properties S.I. |
|---|---|---|---|
| Tensile Strength at Yield, psi (Mpa) | D-638 | 7,000 | 48 |
| Elongation at Break, % | D-638 | 10 | |
| Flexural Strength, psi (Mpa) | D-790 | 11,000 | 76 |
| Flexural Modulus (Tangent), psi (Mpa) | D-790 | 400,000 | 2,758 |
| Izod Impact (Notched), ft-lb/in (J/m) | D-256 | 5.0 | 267 |
| Specific Gravity | D-792 | 1.090 | |
| Heat Deflection Temperature | | | |
| At 264 psi, F (C) | D-648 | 205 | 96 |
| At 66 psi, F (C) | D-648 | 218 | 103 |
| Linear Mold Shrinkage | D-955 | 0.0050 | |

Values shown are averages and not to be construed as specifications.

Fig. 7. ABS-FR Post-Formation properties.

## V. ABS FORMATION

3 monomers of different types, i.e., acrylonitrile, butadiene and styrene, fuse together and copolymerize into ABS, which has combined properties of these individual monomers, and is a much better material on the whole compared to all three reactants.

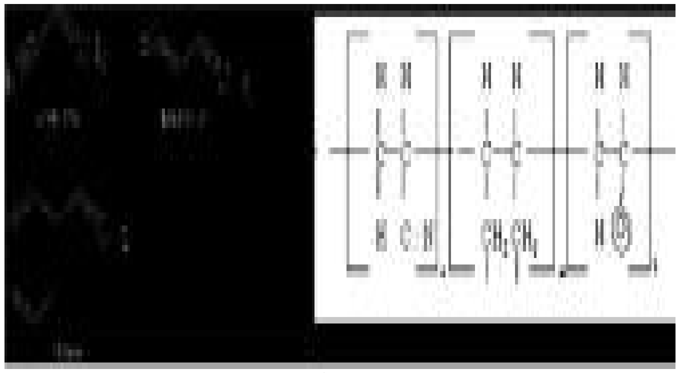

Fig. 8. ABS formation reaction.

## VI. COMPONENT DESIGN AND CALCULATIONS

### A. *Design Objectives*

The core objectives of designing the components are as follows:

*1)* To ensure proper scaling (if needed) from the existing size of the component
*2)* To give proper geometric tolerances for manufacturing of the component
*3)* To satisfy the working conditions for their respective applications

### B. *Design Considerations*

The following are the considerations made before designing the components using the selected materials:

*1)* Size of the component
*2)* Physical stresses (if any) on the component Thermal stresses (if any) on the component
*3)* Working conditions (environment) of the component Durability (life span) of the material
*4)* Chemical reactivity of the material
*5)* Economic feasibility of material Ease or difficulty of manufacture

### C. *The Components Chosen for being replaced with Non-Metallic Material Via this Project are as follows:*

*1)* *Oil Sump Drain-Sieve:*The Addis "Sumpy" is a plastic product that can be used to drain oil out of a car without leaving a big mess. It also helps to store the old oil before disposing of it safely. The problem is that the sump plug can fall out and into the drum. So this model is a 3D printable sieve that can be used to block large particles from going into the drum.

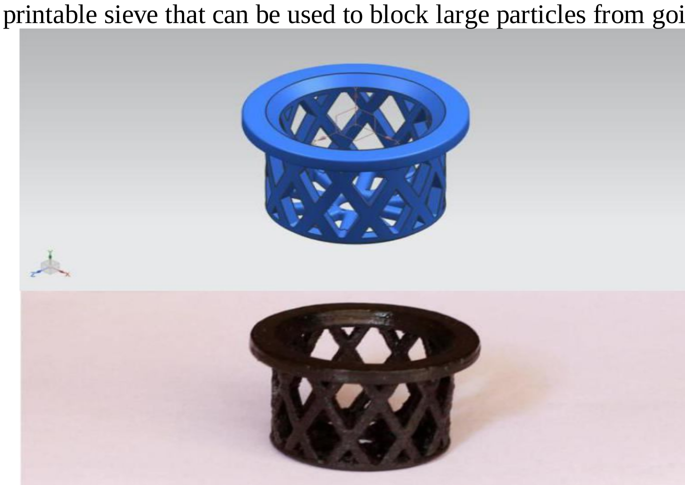

Fig. 9. Oil sump drain sieve.

2) *Air Filter Wingnut:* A wingnut or wing nut is a nut variant with two large metal "wings", one on each side, so that it can be easily tightened and loosened by hand without tools. A similar fastener with a male thread is known as a wing screw or a wing bolt.

Types of conventional manufacturing process of wingnut: cold forged or cold formed produced in regular, light and heavy dimensional series.

*a)* Hot forged solid nuts available in three differentbwing styles.
*b)* Die cast nuts available in three wing styles with variances between regular and heavy dimensional series
*c)* Stamped sheet metal nuts available in three wing styles.

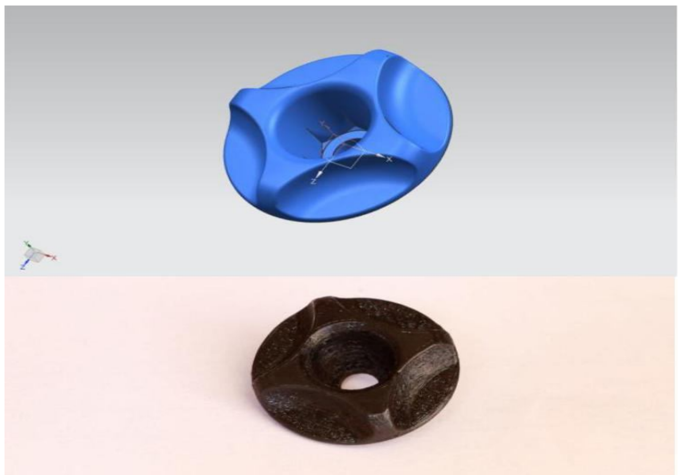

Fig. 10. Air filter wingnut.

3) *Lubricant Flow Relay Splitter:* When one must to diverge a single hydraulic line into two or more identical flow paths, a tee or several tees can be the first solution. However, if the flow resistance in all the branches is not identical, it can vary greatly in each path. Incorporating flow controls at the tee outlets makes it possible to vary resistance and equalize flow in each branch, but as the machine operates, work resistance changes often need constant flow modifications. A device called a flow divider splits the flow and compensates for pressure differences. A flow divider can split flow equally, unequally, and into more than two paths. One design maintains a constant flow for one outlet and directs any excess flow to a second outlet.

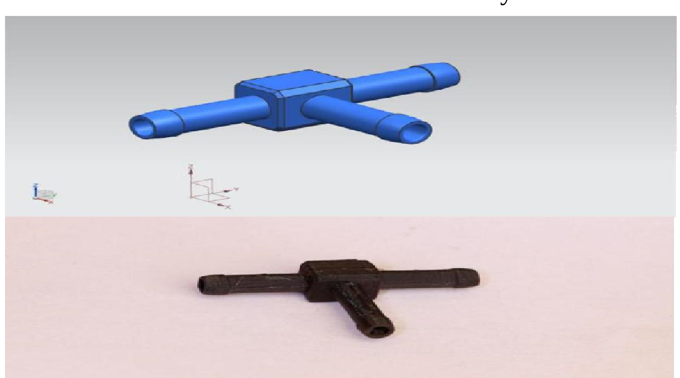

Fig. 11. Lubricant flow relay splitter.

4) *CNC Coolant Venturi Nozzle:* The Venturi effect is the reduction of fluid pressure that results when fluid flows through a constricted section (choke) of a pipe. The Venturi effect is named after Giovanni Battista Venturi (1746–1822), an Italian physicist. A nozzle is a device designed to control the direction or characteristics of fluid flow, especially to increase velocity as

*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887*
*Volume 5 Issue VII, July 2017- Available at www.ijraset.com*

it exits or enters an enclosed chamber or pipe. A nozzle is often a pipe or tube of varying cross sectional area, and it can be used to direct or modify the flow of a fluid (liquid or gas).

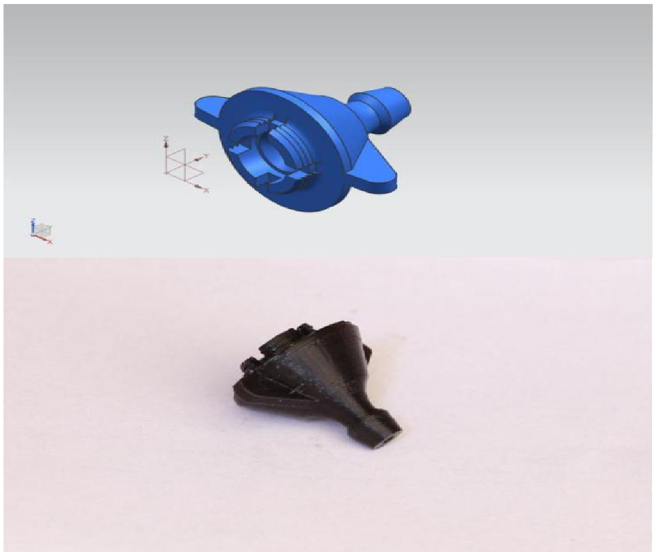

Fig. 12. CNC coolant venturi nozzle.

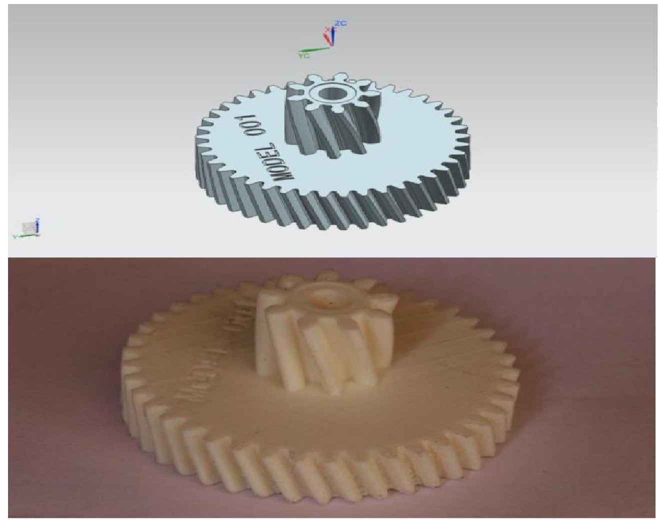


Fig. 13. Mini-lathe gear model #1.

5) *Mini Lathe Gear Models:* Mini lathe is conventional type machine used to fabricate jewellery parts and other mechanical smaller components like nuts, bolts, screws, etc. Mini lathe is used in small scale industries as it is more conventional and economical than other lathes, simply because bigger lathes are not necessary for these end products. Various operations that can be done in this machine include turning, facing, boring, etc.

Fig. 14. Mini-lathe gear model #2.

6) *Gear Design Calculations:*

[redacted]

No. of teeth on the pinion = 9
No. of teeth on the wheel = 38
Helix angle β = 24°
Pressure angle αn = 21°
Normal module = 4

a) *Transverse Module:*

$m_t = \quad \cos \quad = 4\cos 24° = 4.38$ mm (1) *b) Transverse Pressure Angle:*

tan α = tan αcos = tan 21°cos24° = 0.42 (2)

or Transverse pressure angle, αt = tan-1 (0.42) = 22.79° (3)

Axial Pitch (pa):

Axial pitch, pa = π msin24° = 4πsin24° = 30.89 mm

(4)

*c) Pitch Circle Diameter of the Pinion and the Gear (i.e., d1 and d2):*

d
1 = cos ×z1 = 4cos24°×9 = 88.66 mm (5)

d
2 = cos ×z2 = 4cos24°×38 = 166.38 mm (6)

Centre Distance (a):

a = cos × 1+z2 = 4cos24×9+382 = 102 mm (7)

*d) Addendum and dedendum Circle Diameters of the Pinion (i.e., da1 and d2)*

Addendum Circle Diameter of the Pinion:

da1 = ( 1cos +2 ) m (8)

da1 = (9cos24°+2×1) ×4 = 48 mm

Dedendum Circle Diameter of the Pinion:

df
1 = ( 1cos −2 ) m−2c (9)

= Height factor = 1

c = Bottom clearance = 0.25×m = 0.25×4 = 1 mm (10)

df
1 = (9cos −2×1) 4−2×1 = 30mm (11)

## V. CONCLUSION

Metal usage for manufacturing small components which do not experience large loads is unnecessary, which is proved right in this paper. This results in producing same components using unconventional material, which is much lighter than metal, but equally stronger and durable. 3D Printing is not the ideal method for mass-production, but has been used here just to produce one unit of each component to demonstrate the product longevity and quality due to change of material. Also, not all metal components can be replaced by ABS or its counterparts, but only the technically and economically viable ones can, considering the design, working conditions and stresses subjected to. Reasons for failure of Gear Model #2:

*A.* Inability to withstand forces produced due to torque of second shaft of mini lathe's gearbox.

*B.* Insufficient resilience for the applied moment.

*C.* Unideal hollow shaft thickness for retention of strength when manufactured additively.

## VI. ACKNOWLEDGMENT

We express our gratitude to Mr. P. Sriram, Chairman, CIT, and all trust members, for providing the facility and opportunity to do this project. We sincerely thank our Guide, Dr. P. L. N. Ramesh, Principal, CIT, for having provided us valuable guidance, resources and timely suggestions throughout our work. We wish to extend our gratitude to Mr. Surendranath Reddy, CEO, 3D*ing* & REDD Robotics, for his guidance and support in facilitating the fabrication of our project. We also wish to extend our sincere thanks to all Faculty Members of the Department of Mechanical Engineering, for their valuable suggestions and their kind co-operation for the successful completion of our project.

## REFERENCES

[1] Joe Himenz, "3D Printing Jigs, Fixtures and Other Manufacturing Tools," Stratasys Fortus, 2011.

[2] Christopher D. Winnan, "Adventures in 3D Printing: Limitless Possibilities and Profit Using 3D Printers," December 2013.

[3] "3D printers: The future has already begun," SIEMENS Industry Journal, Issue:1, 2013.

[4] "3D Printing Technology (Over the Years)", The National Informatics Centre Uttar Pradesh State Unit e-Journal, 2010.

[5] Stefan Bechtold, "3D Printing and the Intellectual Property System," Wipo Journal, Economic Research Working Paper No.28, 2015.

[6] Walter P., Huson D., Parraman C., Stanić M, "3D Printing in Colour: Technical Evaluation and Creative Applications," Impact 6 International Printmaking Conference, September 2009.

[7] Pitchaya Sitthi-Amorn, Javier E. Ramos, Yuwang Wang, Joyce Kwan, Justin Lan, Wenshou Wang, Wojciech Matusik, "MultiFab: A Machine Vision Assisted Platform for Multi-material 3D Printing," SIGGRAPH, 2015.

[8] R. Kumaravelan, V. C. Sathish Gandhi, S. Ramesh, M. Venkatesan, "Rapid Prototyping Applications in Various Field of Engineering and Technology," International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8, No:3, 2014