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FABRICATION OF LEAF SPRING PLASTIC BUSH BY FDM PROCESS AND ITS COMPARATIVE STUDY ON MECHANICAL PROPERTIES AND COST

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Abstract

A leaf spring is a basic type of spring that is frequently used for the suspension in wheeled vehicles. It mainly consists of metal plates or leaves, master leaf, centre bolt, U-bolt, rebound clip, spring eye, hanger, shackle and bush. In this report, we will briefly discuss the simplest part of the spring, which is the plastic bush. It is one of the elementary parts which join leaf spring to the chassis of the vehicle. Main function of leaf spring plastic bush is to reduce friction and noise between shackle and hanger. It also avoids shearing between these two metallic components. In this research work, leaf spring plastic bush will be obtained from market which is manufactured by injection molding. Further, reverse engineering of this plastic bush will be done to manufacture it by 3D printing. For this purpose, ABS and polycarbonate filaments will be used. Mechanical properties such as strength and hardness will be compared for the samples fabricated by injection molding and 3D printing. Also, life cycle analysis and cost analysis will be done to get an idea about the efficiency and feasibility of 3D printing technology.

Keywords: Leaf Spring Plastic Bush; Auto Parts Manufacturing; Reverse Manufacturing; Fused Deposition Modeling.

1.0 INTRODUCTION

To balance a towed weight and ensure that it stays on the ground, leaf springs are a great solution. A leaf spring is a thin, rectangular-sectioned length of spring steel that is fashioned like an arc. The axle is placed in the middle of the arc in the most typical layout, and the loops generated at each end are used to link the vehicle to the chassis. A leaf spring may be created for very large vehicles by stacking numerous leaves on top of one another in multiple levels, frequently with increasingly shorter leaves. With leaves ranked in descending order of length, the longest leaf is sometimes referred to as the main, master, or no. 1 leaf. The eyes at the end of the leaf spring are formed into the master leaf. Apart from the master leaf, the other leaves often taper at both end (Sheldon Axle Company, 1912). The alloys 55Si7, 60Si7, 65Si7, 50Cr4V2, and 60Cr4V2 are suitable for the manufacturing of leaf springs (Bureau of Indian Standards, 1995).

2.0 REVERSE MANUFACTURING

Reverse manufacturing is the process of duplicating an existing component, subassembly, or product. For, this purpose computer model is created of existing component. Majority of the AM processes use 3D scanners to create digital model of existing components. Further product is manufactured by more efficient technology using this digital model. In this report, we will check additive manufacturing can be this more efficient technology or not.

Fig.1: Components of leaf spring (Available online: https://www.theengineerspost.com/leaf-spring-suspension)

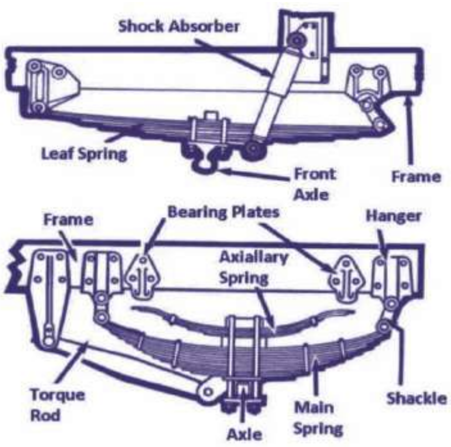
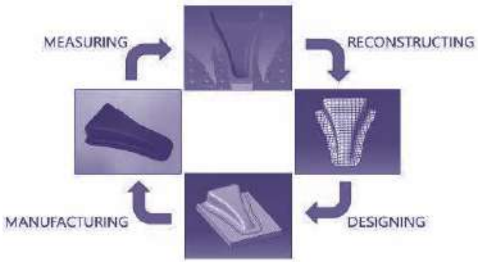


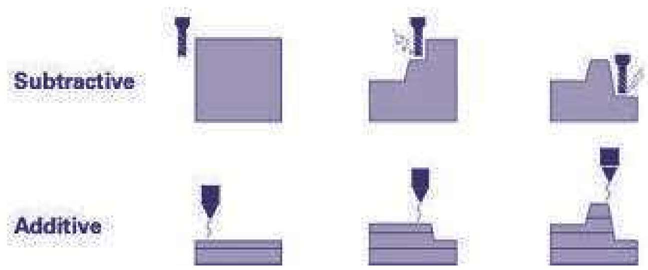
Fig. 2: Process of reverse manufacturing (Kim et al., 2017)



3.0 ADDITIVE MANUFACTURING

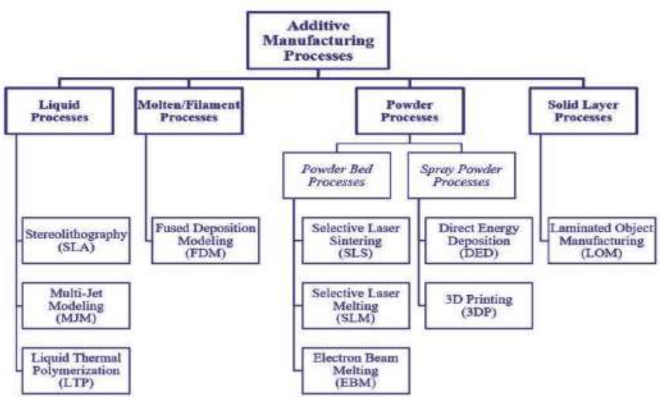
According to ASTM International (ISO/ASTM 52900, 2015), Additive Manufacturing can be defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies".

Fig. 3: Difference between traditional and additive manufacturing



4.0 CLASSIFICATION OF ADDITIVE MANUFACTURING

Fig. 4: Various additive manufacturing processes



In this figure, various powder processes are shown which are mainly used for metal 3D printing. Liquid processes can cure only photo sensitive resin. Since, we are fabricating bush of plastic material. Hence, we will study the Fused Deposition Modeling technology which is highly recommended for plastic materials.

5.0 ROLE OF ADDITIVE MANUFACTURING IN AUTOMOTIVE INDUSTRY

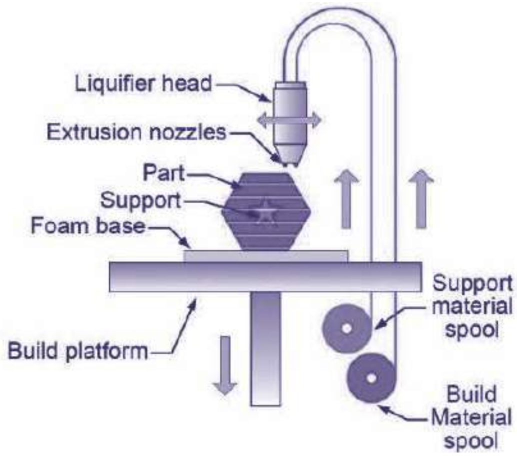
AM processes eliminate die setup and reduce fixed cost for different designs. Hence, a big range of auto parts can be easily fabricated. These processes can reduce weight of various automotive parts significantly with maintaining all the required strengths to enhance fuel efficiency. These processes enable on demand and in-house production, which reduces material procurement costs, shipping costs and inventory needs. It enables customizing of auto accessories according to consumer demand to make it more aesthetic. There is very less material wastage and no tool requirement in these processes (Abhishek Arora and Kailash Choudhary, 2023).

Fig. 5: Reverse manufacturing of automobile components using additive manufacturing

6.0 FUSED DEPOSITION MODELLING (FDM)

FDM is comes under the category of molten filament processes. As the name suggest, filament is melted and directed to create the final object. In a typical FDM system, a filament is melted and extruded onto a build surface along a predetermined path. As the material is extruded, it starts to cool and form a solid surface to provide foundation for the upcoming layer of material to be built over it. This is performed layer by layer until the whole object is created.

Fig. 6: Fused deposition modeling (F. Ning et al., 2015)



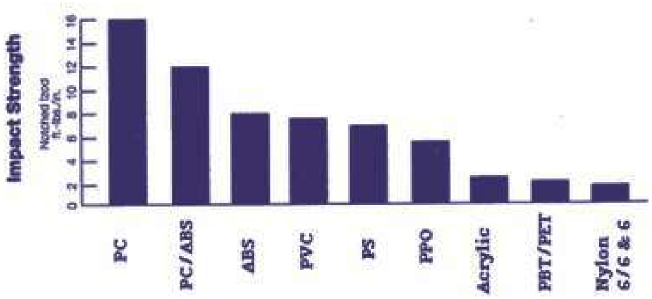
If the object design is complicated or there is any overhang then support material nozzle deposit the support material so that printing of build material in air can be avoided. At the end of object creation process, this extra support material is removed.

7.0 FILAMENTS USED IN FUSED DEPOSITION MODELING

The mechanical properties of final object majorly depends on the three things - Design of the object, Process parameters used in the FDM process & Material of the filament used. Among these factors filament material has major impact on the mechanical properties of the final object because design of object can't be changed otherwise it will not perform basic functions. Process parameters also can be set for 100% density. But, material knowledge is must for a FDM user.

(Available online: https://www.cavitymold.com/nylon-vs-abs-injection-molding)

Fig. 7: Impact strength of various thermoplastics



The most common printing material for FDM is ABS, a common thermoplastic that's used to make many consumer products, from LEGO bricks to whitewater canoes (Palermo E., 2013). ABS gives you all the performance you need in engineering plastic. Just don't increase the heat. ABS has service temperature of 80 to 100 degree Celsius. Maximum continuous use temperature for ABS is 71 degree Celsius. Except this limitation, ABS has very impressive mechanical properties like low moisture absorption, high dimensional stability, smooth surface, high brightness, chemical resistance, strain resistance and low cost.

But polycarbonate (PC) has also exceptional mechanical properties as follows (Available online: https://www.xometry.com/resources/materials/polycarbonate-vs-abs):

1. PC is strong and durable. It can also be bent without breaking.
2. PC has highest impact resistance among all the filaments available for the 3D printing.
3. Polycarbonate is transparent in nature.
4. PC has glass transition temperature of 150°C which makes it suitable for high-temperature.

In next section, we will check PC can be better replacement of ABS or not. Material properties of PC will be discussed briefly and comparison will be done with ABS. Also, life cycle analysis and cost analysis will be done for 3D printed PC bush and injection molded ABS bush.

8.0 FABRICATION PROCESS

In this section, fabrication process of bush will be described. For measuring mechanical properties of this plastic bush different samples will also be fabricated based on ASTM standard of different mechanical tests. Fabrication will be done using FDM machine namely "4Ds Smart One" facilitated by "Adroitec Information Systems Pvt. Ltd, Noida" and available at MNIT, Jaipur. Fabrication Steps of Leaf Spring Plastic Bush are as follows:

1. **Obtain Bush from Market:** Bush is available on 46/- maximum retail price in market. This cost will be used in cost analysis in the next chapter. Bush is of TDH brand manufactured by Swaran Auto Industries, Ludhiana.

Fig. 8: Leaf spring plastic bush of TDH

(a) Packed **(b) Unpacked**

2. **Measurement of the Bush:** Bush is hollow cylindrical in shape having following dimensions-

Height- 43 mm, Outer diameter- 22 mm, Wall thickness- 2 mm, Inner diameter- 18 mm.

3. **Creating a Digital Model:** Now, we know the dimension and geometry of the bush very next step is to create its digital model. For this purpose, creo parametric is used. Further, this 3D model is saved in STL Format.

4. **Generating G-Code:** STL file is to be converted in G-code by Simplify3D software to give it to the 3D printer which directs the path of nozzle to print final part. Following parameters are to be set to achieve better mechanical properties: Orientation- XZ, Layer height- 0.2 mm, Internal infill pattern- Rectilinear, Infill Percentage- 90%, Raft Base Layers- 2, No support required, Printing speed – 60 mm/sec, Extruder temperature- 260ºC, Bed temperature – 100ºC, Top solid layer- 4, Bottom solid layer- 4, Outer periphery lines- 2, Nozzle diameter- 0.40 mm and all other default parameters were used.

5. **Preparing 3D Printer to Work:** After generating G-code, 3D printer is prepared for work. For this purpose, Base plate is cleaned and mounted properly to start printing over it. Acetone plus ABS solution is to be spread over base plate. It works as adhesive so that during printing bush not get detached from surface of base plate. Filament of PC is to be placed at the designated place in 3D printer. Nozzle should also be checked.

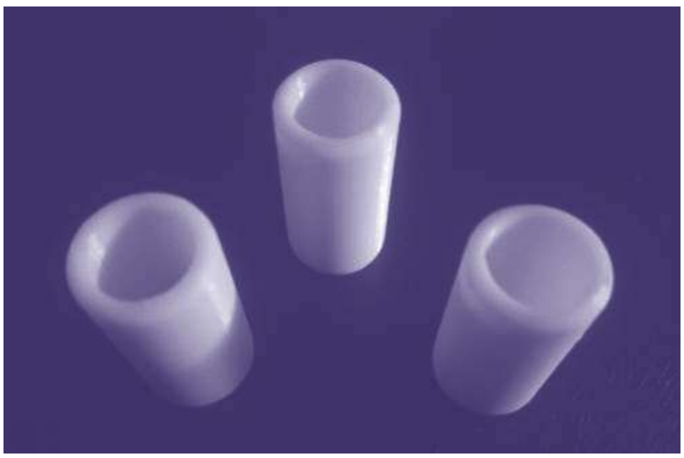
6. **Printing 3D Object:** Now, the printing is to be started. After setup of the printer, bushes are printed automatically the person can be engaged in other work for that time to increase the efficiency. Still one person should be always present there to take care of any malfunction happen during printing. Hence, it is

always recommended to place 5-6 3D printers simultaneously in a room to increase efficiency of manpower.

Fig. 9: 3D printing of the leaf spring plastic bush

7. Final Processing of Object: After printing the bush, next step is to remove it from base plate. This step is again to be done manually. Almost no post processing of bush is required because support material was not used during printing and also there was very less area of bush which was in contact with base plate. By repeating the same steps, 3 bushes have been obtained as shown in figure.

Fig. 10: 3D printed polycarbonate leaf spring plastic bush



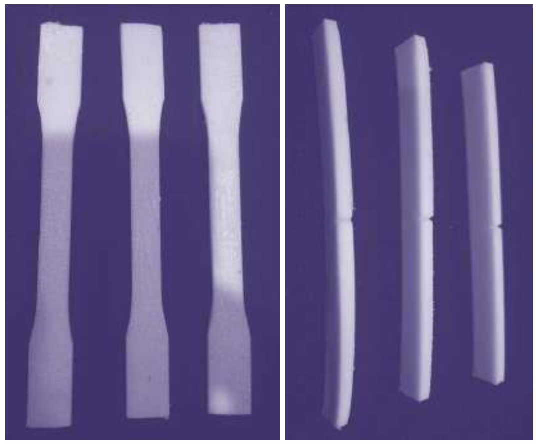
FABRICATION OF SAMPLES FOR DIFFERENT MECHANICAL TESTS

After fabricating the bushes, samples for different mechanical tests are to be obtained using same process steps. All parameters should be used same as used during the printing of bush so that true values of different mechanical properties of bush can be obtained. Sample dimensions should be based on following standards:

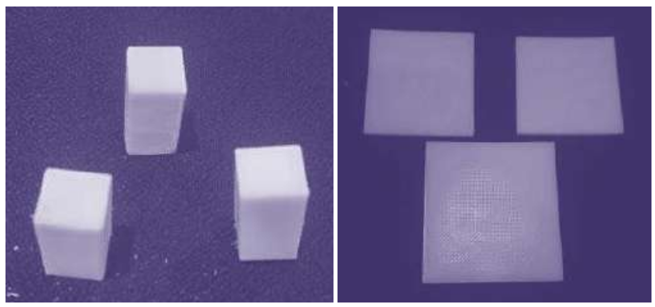
For, Tensile Test- ASTM D638
Compressive Test- ASTM D695

Impact Test- ASTM D6110
Hardness Test- ASTM E384

Fig. 11: 3d printed polycarbonate specimen for various mechanical test



(a) Tensile dog-bone test specimen (b) Compressive block test specimen



(c) Charpy impact test specimen (d) Vickers hardness test specimen

9.0 MECHANICAL STRENGTH ANALYSIS OF ABS AND PC

1. Tensile and Compressive Testing

Tensile test peak load (P_{max}) = 1538 N
(Value obtained from UTM)

Original cross- sectional area of dog bone sample (A_0)
$= \text{Gauge width} \times \text{Thickness}$

Hence, $A_0 = = 13 \times 3.2\ mm^2 = 41.6\ mm^2 = 4.16 \times 10^{-5}\ m^2$

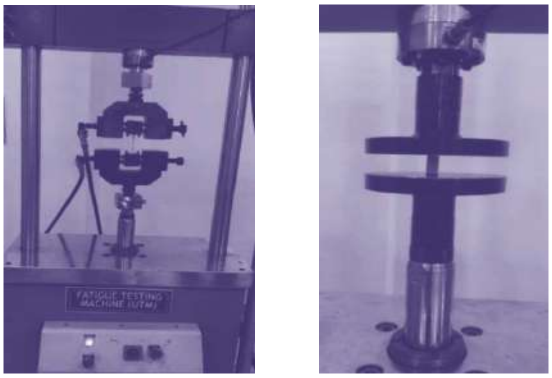
$$\text{Ultimate tensile strength} = \frac{\text{Maximum load}}{\text{Original cross sectional area}} = \frac{P_{max}}{A_0}$$

$$= \frac{1538}{4.16 \times 10^{-5}} = 369.71 \times 10^5\ N/$$

Since, $1\ N/m^2 = 10^{-6}$ Mpa
Hence, Ultimate tensile strength = $369.71 \times 10^5 \times 10^{-6}$ Mpa
= 36.97 Mpa ≈ 37 Mpa

Fig. 12: Tensile and compressive testing on universal testing machine

(a) Tensile test (b) Compressive test



Compressive test peak load (P_{max}) = 9045 N (Value obtained from UTM)

Original cross- sectional area of compressive block sample (A_0)

$= \text{Width} \times \text{Thickness} = 12.7 \times 12.7\ mm^2 = 161.29\ mm^2 = 16.13 \times 10^{-5}\ m^2$ Compressive strength =

$$\frac{\text{Maximum load}}{\text{Original cross sectional area}} = \frac{P_{max}}{A_0} = \frac{9045}{16.13 \times 10^{-5}} \times 10^{-6} = 56 \text{ Mpa}$$

2. Hardness and Impact Testing

Fig. 13: Hardness value for polycarbonate samples

(a) Maximum hardness value (b) Minimum hardness value

Since, maximum hardness value = 72.0
minimum hardness value = 68.4
Hence, Vickers hardness value =

$$\frac{\text{Maximum hardness value} + \text{Minimum hardness value}}{2}$$

$$= \frac{72.0+68.4}{2} = 70.2$$

Also, obtained value of charpy impact test was 3.5 J/cm².

10.0 A COMPARISON BETWEEN MECHANICAL PROPERTIES OF MOLDED AND 3D PRINTED PC AND ABS

In the table 1 mechanical properties of ABS molded, PC molded and PC 3d printed samples are shown. Here, different values for 3d printed polycarbonate were obtained in previous section and different values for ABS molded and PC molded has been taken from the MatWeb material property data (Available online: https://www.matweb.com).

Table 1: Material properties of ABS and PC

Mechanical Test	ABS Molded	PC Molded	PC 3D Printed
Tensile strength (MPa) (Ultimate)	2.60 - 73.1 Average value = 40.7	28.0 - 75.0 Average value = 66.3	37
Compressive yield strength (MPa)	53	18.0 - 86.2 Average value = 61.2	56
Impact strength (J/cm²) (Charpy Impact Notched)	0.700 - 5.00 Average value = 2.55	0.900- 8.80 Average value = 6.42	3.5
Vickers hardness	11.5	14	70.2
Hardness test(Rockwell R)	68-118	114 - 126	
Water absorption (%)	0.0500 - 1.00 Average value = 0.414	0.0200 - 0.300 Average value = 0.173	
Moisture absorption at equilibrium (%)	0.000 - 0.300 Average value = 0.217	0.120 - 0.350 Average value = 0.151	

Hence, molded polycarbonate is clear winner in every mechanical property. Also, most of the mechanical properties of 3d printed PC are higher in comparison to mechanical properties of molded ABS. Properties of 3d printed PC can be further improved by optimization of 3d printing parameters (layer thickness, infill pattern, printing speed etc). This data show us that 3d printed PC can be used in wide applications of molded ABS wherever small batch size of objects is required. Hence, initial cost and initial setup time of molding process can be eliminated.

11.0 LOAD TEST AS PER THE APPLICATION OF BUSH IN THE LEAF SPRING

This is non-standard testing method which is directly performed over the bushes as per the application of bush. All the values obtained in this test are only for the comparison purpose.

Fig. 14: Placement of bush in shackle as per its application

Fig. 15: Assembly of shackle pin and leaf spring plastic bush

(a) ABS molded bush (b) ABS 3D printed bush (c) PC 3D printed bush

When sudden jerks occur on road shackle pin collides with leaf spring eye as shown in fig. 14. It results in wearing of the plastic bush in between them. To compare life cycle of the different bushes (Molded ABS, 3D printed ABS, 3D printed polycarbonate) in such operational conditions, we will first assemble each bush over metallic shackle pin as shown in fig.15. This assembly is to be placed in UTM one by one. In UTM a compressive load will act over this. The peak load at each bush fails is to be measured which is shown in the table below.

Table 2: Mechanical strength analysis of ABS and PC bush

Type of Bush	ABS Injection Molded Bush	ABS 3D Printed Bush	PC 3D Printed Bush
Peak load at each bush fails (Newton)	8090	7640	8550

Hence, we can conclude that PC 3D printed bush sustained for highest load. Hence, PC 3D printed bush has superior mechanical properties than existing bush.

12.0 LIFE CYCLE ANALYSIS OF ABS INJECTION MOLDED AND PC 3D PRINTED BUSH

For Life cycle analysis a survey was done. A mechanic was provided with existing ABS Injection Molded Bush, ABS 3D Printed Bush and PC 3D Printed Bush. It was studied that once bush is employed in any vehicle after how much time it is entering into garage again for the bush replacement. Following data were obtained for each bush:

Table 3: Data obtained from 1st mechanic over 24 vehicles

ABS Injection Molded Bush	ABS 3D Printed Bush	PC 3D Printed Bush
180 days	166 days	160 days
168 days	177 days	157 days
153 days	148 days	188 days
163 days	150 days	178 days
149 days	160 days	200 days
198 days	157 days	190 days

Average life of ABS Injection Molded Bush = $\frac{180+168+153+163+149+198}{6} = \frac{1011}{6}$ = 168.5 days

Average life of ABS 3D Printed Bush = $\frac{166+177+148+150+160+157}{6} = \frac{958}{6}$ = 159.67 days

Average life of PC 3D Printed Bush = $\frac{160+157+188+178+200+190}{6} = \frac{1073}{6}$ = 178.83 days

Hence, average life of PC 3D Printed Bush is highest this validate our data obtained from non standard self designed testing procedure.

13.0 COST ANALYSIS OF ABS INJECTION MOLDED BUSH AND PC 3D PRINTED BUSH

MRP of existing bush is 46/- which is sold in market at rate of 40 to 45 on different shops. It is imported from Delhi at the price of 35/-. If we consider these rates as a retailer or wholesaler point of view which imports it from Delhi then our fabrication cost should be less than 35 rupees. As manufacturing cost is unknown for us, we will focus on import cost so that localized demand can be fulfilled at lower prices. Also, dependency over a few manufacturers can be reduced.

13.1 Annualized Demand of Bush

If we consider annualized demand of the bush in tier-2 city like Jodhpur then it is as follows:

4 bushes are replaced simultaneously in a vehicle.

There are total 4 mechanics which daily repair 1 to 2 three-wheeler vehicle's leaf springs

and 2 mechanics which daily repair 2 to 3 three-wheeler vehicle's leaf springs.

and 2 mechanics which daily repair 2 to 3 three-wheeler vehicle's leaf springs.

Since, $minimum\ daily\ demand$

$$= No.of\ bushes\ repaired\ simultaneously \times No.of\ mechanics\ repairing\ leaf\ springs \times Minimum\ no.of\ leaf\ springs\ repaired$$

Hence, $minimum\ daily\ demand =$

$$(4 \times 4 \times 1) + (4 \times 2 \times 2) = 16 + 16 = 32\ units$$

Since, $maximum\ daily\ demand =$

$$No.of\ bushes\ repaired\ simultaneously \times No.of\ mechanics\ repairing\ leaf\ springs \times Minimum\ no.of\ leaf\ springs\ repaired$$

Hence, $maximum\ daily\ demand =$

$$(4 \times 4 \times 2) + (4 \times 2 \times 3) = 32 + 24 = 56\ units$$

Since, $average\ daily\ demand = \frac{Minimum\ daily\ demand + Maximum\ daily\ demand}{2}$

$$= \frac{32 + 56}{2} = 44\ units$$

Hence, $average\ yearly\ demand = 365 \times Avg.daily\ demand = 365 \times 44 = 16060\ units$

Since, Delhi rate of every bush is 35 rupees.

Hence, $yearly\ demand\ (in\ terms\ of\ rupees) = 16060 \times 35 = 562100/-$

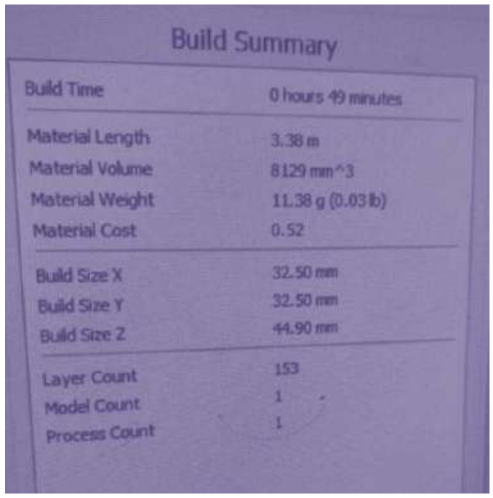
If we offer our 3D Printed PC bush in 33 rupees to capture t he market very fast

Then, $total\ possible\ yearly\ revenue = 16060 \times 33 = 529980/-$

13.2 Manufacturing Cost of Polycarbonate Bush

Fig. 16: Build summary of 3D printed polycarbonate bush

(a) For single bush



(b) For the batch of 5 bushes

Based on the bed size of the 3D printer we can print 5-8 bushes simultaneously. It reduces the setup time which required before every print. But this practice has also some drawbacks:

1. If any malfunction happens like buckling, nozzle clogging etc during printing, the last layer of all bushes solidified and printing work over these solidified layers can't resume. We have to restart the print again. Hence, material and time both wasted for that period.

2. Malfunction occurs is mainly due to the detachment of bush from base plate for this purpose we have to take higher raft (pink shaded region in fig.17) to ensure adhesion between bush and base plate which increase the printing time. Build time of single bush is 49 minutes as shown in fig 16(a). Hence, it should be 49×5= 4 hours 5 minutes for the 5 bushes but actual build time is 4 hours 39 minutes (fig 16(b)) due to increased raft height. Hence, setup time saved is consumed here. Also, layers count increase from 153 to 156 (fig.16) which increase the material consumption.

- **Response Surface Methodology (RSM)**

- $Response\_Variable = f(input\_variables)$

- RSM aims to model the relationship between input variables and response variables using mathematical functions.

- **Optimization Algorithms**

- $Genetic\_Algorithm = f(objective\_function, constraints)$

- Genetic algorithms iteratively explore parameter space to find optimal combinations of parameters based on fitness criteria.

NOVEL TECHNIQUES

• "Machine Learning-Based Material Selection for SLS": Predictive Models for Material Suitability and Performance" This research focuses on developing machine learning models that can analyze material properties and predict their suitability for SLS. By training the models on a diverse dataset of materials and their corresponding SLS performance, it becomes possible to expedite the material selection process and identify promising candidates for optimized SLS fabrication.

• "Multi-objective Optimization for SLS": Finding the Best Balance Between Mechanical Properties, Surface Quality, and Production Cost in SLS" A multi-objective optimization strategy is used in this study to find the best balance between mechanical properties, surface quality, and production cost in SLS. It becomes possible to identify parameter combinations that achieve the desired trade-offs between these competing objectives by formulating the optimization problem and utilizing evolutionary algorithms or other optimization methods.

• "Advanced Material Characterization Techniques for SLS": This study uses cutting-edge material characterization methods like X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and atomic force microscopy (AFM) to predict the properties and microstructure of SLS materials. By combining these techniques with computational models or machine learning, it becomes possible to gain a deeper understanding of the behavior of the material during the SLS process and optimize the selection of the material accordingly.

• "In-situ Monitoring and Control for SLS": Real-time Feedback and Adaptive Process Optimization" This study focuses on developing in-situ monitoring techniques for SLS, enabling real-time feedback on process parameters and material behavior. By incorporating sensors and feedback control mechanisms into the SLS setup, it becomes possible to dynamically adjust the process parameters based on the observed responses, leading to improved part quality and process stability.

• "Material Recycling and Sustainability in SLS": Optimizing Material Reusability and Environmental Impact" This research addresses the growing concern of sustainability in SLS by exploring techniques for material recycling and minimizing the environmental impact of the process. Investigating methods for efficient powder recycling, evaluating the effect of recycled material on part quality, and optimizing the recycling process parameters can contribute to sustainable SLS manufacturing practices.

RESULTS AND DISCUSSION

The research's findings are presented in an organized and clear manner in the results and discussion section. It focuses on the properties and characteristics of the various materials investigated and examines the effects of various processing parameters on the SLS process and final part quality.

PROPERTIES AND CHARACTERISTICS OF DIFFERENT MATERIALS

Polymers, metals, and composites, all of which are frequently used in SLS, were the subjects of the study. Material characterization methods were used to carefully examine each material's properties and characteristics. The materials' tensile strength, flexural modulus, and impact resistance were discovered through mechanical testing. Warm investigation gave experiences into their liquefying and glass change temperatures, while microscopy methods considered the assessment of their microstructure and surface morphology.

Table 2: Material Properties

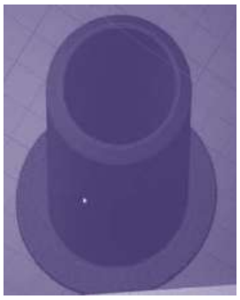
Material	Tensile Strength (MPa)	Flexural Strength (MPa)	Thermal Conductivity (W/mK)
Nylon 12	48	72	0.25
Polycarbonate	65	80	0.20
Polypropylene	40	55	0.18

According to the findings, various materials had distinct advantages and disadvantages when used in SLS applications. Polymers, for instance, were able to produce functional parts with good mechanical properties thanks to their excellent processability and extensive material options. Metals, on the other hand, were suitable for applications requiring heat dissipation and high performance due to their high strength and thermal conductivity. The increased strength-to-weight ratio of composites made it possible to produce lightweight yet structurally sound components.

EFFECTS OF PROCESSING PARAMETERS ON THE SLS PROCESS AND PART QUALITY

The study also looked into how various processing parameters affected the SLS process and the quality of the finished products. The effects of systematically varying laser power, scan speed, layer thickness, and powder bed properties on part quality, dimensional accuracy, and mechanical properties were examined.

Fig. 17: Raft provided to the bush



Hence, we will print the bushes one by one although some 3D printer experts can take the batch of 5-8 bushes. For the time optimization, we will print it in 5 FDM machines simultaneously. Five 3D printers are also available at the facility.

Production Speed-

Table 4: Typical routine of the work man

Time on Clock	Work Man Job
6 am - 6.10 am	Setup of 1st FDM machine
6.10 am - 6.20 am	Setup of 2nd FDM machine
6.20 am - 6.30 am	Setup of 3rd FDM machine
6.30 am - 6.40 am	Setup of 4th FDM machine
6.40 am - 6.50 am	Setup of 5th FDM machine
6.50 am - 7.00 am	Inspection, Supervision and relax
7.00 am – 7.10 am	Removal of printed bush from 1st FDM machine and setup for next printing
7.10 am – 7.20 am	Removal of printed bush from 2ndFDM machine and setup for next printing
7.20 am – 7.30 am	Removal of printed bush from 3rd FDM machine and setup for next printing
7.30 am – 7.40 am	Removal of printed bush from 4th FDM machine and setup for next printing
7.40 am – 7.50 am	Removal of printed bush from 5th FDM machine and setup for next printing
7.50 am – 8.00 am	Inspection, Supervision and relax

Build time = 49 minutes, Setup time = 10 minutes (as shown in fig 16(a) and Table 4)

Total time for printing of single bush = build time + setup time = 49 + 10 = 59 minute ≈ 1 hour

If a single person can run 5 machines simultaneously. Then, No. of bushes printed per hour = 5

Based on the table 4, if two shifts of 9-9 hours are run then Total available time = 18 hours

Setup time in day beginning = 1 hour (Time between 6 am – 7 am, as shown in table 4)

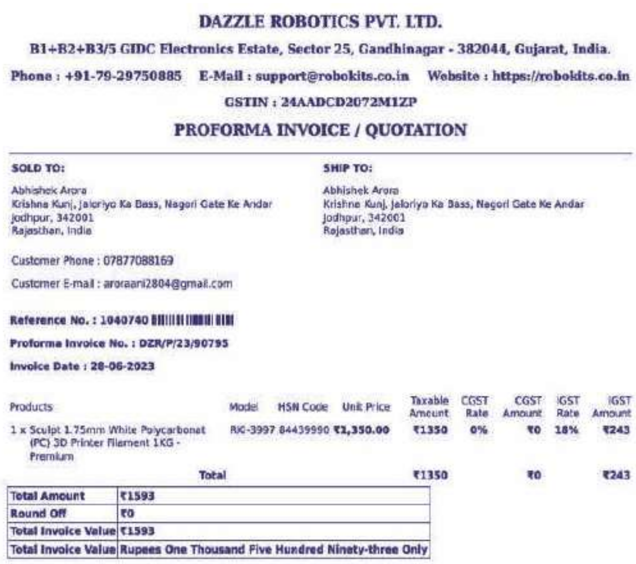
Extra time if any malfunction happens for both shifts = 0.5 + 0.5 = 1 hour

Then, daily utilized time of single machine = Total available time - (Setup time + Extra time if any malfunction happens) = 18 – (1+1) = 16 hours

Hence, daily production by 5 machines = 5 × 16 = 80 units

Material Cost of PC-

Fig. 18: PC filament spool cost



DAZZLE ROBOTICS PVT. LTD.
B1+B2+B3/5 GIDC Electronics Estate, Sector 25, Gandhinagar - 382044, Gujarat, India.
Phone : +91-79-29750885 E-Mail : support@robokits.co.in Website : https://robokits.co.in
GSTIN : 24AADCD2072M1ZP

PROFORMA INVOICE / QUOTATION

SOLD TO:
Abhishek Arora
Krishna Kunj, Jaloriya Ka Bass, Nagori Gate Ke Andar
Jodhpur, 342001
Rajasthan, India

SHIP TO:
Abhishek Arora
Krishna Kunj, Jaloriya Ka Bass, Nagori Gate Ke Andar
Jodhpur, 342001
Rajasthan, India

Customer Phone : 07877088169
Customer E-mail : aroraani2804@gmail.com

Reference No. : 1040740
Proforma Invoice No. : DZR/P/23/90795
Invoice Date : 28-06-2023

Products	Model	HSN Code	Unit Price	Taxable Amount	CGST Rate	CGST Amount	IGST Rate	IGST Amount
1 x Sculpt 1.75mm White Polycarbonat (PC) 3D Printer Filament 1KG - Premium	RK-3997	84439990	₹1,350.00	₹1350	0%	₹0	18%	₹243
Total				₹1350		₹0		₹243

Total Amount	₹1593
Round Off	₹0
Total Invoice Value	₹1593
Total Invoice Value	Rupees One Thousand Five Hundred Ninety-three Only

PC filament spool cost = 1593/- Weight of PC spool = 1 kg (as shown in fig. 18)

Weight of bush = 11.38 grams (as shown in fig. 16(a))

Hence, material cost per unit of bush

$$= \frac{Weight\ of\ bush}{Weight\ of\ polycarbonate\ spool} \times PC\ filament\ spool\ cost = \frac{11.38}{1000} \times 1593 = 18.13 \text{ rupees} \quad \ldots(1)$$

Manpower Cost –

Minimum wages for semi skilled worker in Rajasthan = 271/- per day

For 2 shifts, manpower cost per day = 271 × 2 = 542/-

Manpower cost per bush = $\frac{manpower\ cost\ per\ day}{Daily\ production} = \frac{542}{80}$ = 6.77/- …(2)

Electricity Consumption of FDM –

As per Michael Dwamena, "The average 3D printer with a hotend at 205°C and heated bed at 60°C draws an average power of 70 watts. For a 10-hour print, this would use 0.7kWh which is around 9 cents. The electric power your 3D printer uses depends mainly on the size of your printer and the temperature of the heated bed and nozzle" (Available online: https://3Dprinterly.com). By this data, we can conclude that 0.7 units are used for 10-hour print.

Hence, per hour consumption is 0.07 units.

Since, rate of electricity = 7.95 rupees per unit

Hence, electricity cost per machine per hour = Rate of electricity × Per hour consumption

= 7.95 × 0.07 = 0.5565 rupees

Electricity cost per unit of bush =

$$\frac{Electricity\ cost\ per\ machine\ per\ hour}{No.of\ units\ produced\ per\ machine\ per\ hour} = \frac{0.5565}{1} = 0.5565/\text{-}..(3)$$

Maintenance Cost-

This cost includes the maintenance of FDM machine, nozzle changing cost, machine depreciation cost. Since a basic FDM machine comes around 16000 rupees and it can be easily operated 8 hours per day with less maintenance requirement. Also, many websites like rapid direct (Available online: https://www.rapiddirect.com/blog/3D-printing-service-cost) suggests that an average FDM printer requires maintenance around 100 dollars every year.

Hence, we will assume Maintenance cost per year = 8000 rupees

Maintenance cost per machine per hour

$$= \frac{Maintenance\ cost\ per\ year}{No.of\ hours\ machine\ operated\ per\ day \times No.of\ days\ in\ a\ year\ machine\ operated} = \frac{8000}{16*365} = 1.37 \text{ rupees}$$

$$\text{Maintenance cost per unit of bush} = \frac{Maintenance\ cost\ per\ machine\ per\ hour}{No.of\ units\ produced\ per\ hour} = \frac{1.37}{1} = 1.37 \text{ rupees} \ldots(4)$$

Now, all the associative costs are calculated.

Total Cost-

By (1), material cost per unit of bush = 18.13 rupees

By (2), manpower cost per unit of bush = 6.77 rupees

By (3), electricity cost per unit of bush = 0.5565 rupees

By (4), maintenance cost per unit of bush = 1.37 rupees

Hence, total cost per unit of bush = 18.13 + 0.5565 + 6.77 + 1.37 = 26.82

If transportation, packaging and all other costs are maximum 1.18 rupees for every bush then maximum total cost is 28 rupees which is less than our actual selling cost of 33 rupees.

13.3 Annualized Profit

If we calculate the different cost based on annualized demand

Since, annualized demand = 16060 units (obtained previously)

Hence, annualized sales revenue = Annualized demand × Selling price

= 16060 × 33 = 529980/-

Annualized total cost = Annualized demand × total cost per unit

= 16060 × 28 = 449680/-

Annualized total profit = Annualized sales revenue - Annualized total cost

= 529980 – 449680 = 80300 rupees

As we have seen our daily capacity is 80 units.

Hence, yearly production = 365 × 80 = 29200 units

$$\text{Machine utilization} = \frac{Annualized\ demand}{Yearly\ Production} = \frac{16060}{29200} = 0.55 \text{ years} = 201 \text{ days}$$

Hence, annualized demand can be fulfilled by the production run of 201 days. If it was injection molding then die would remain idle for rest of days but 3D printing give you advantage of zero idleness of machine because any other part can be fabricated for the rest of 164 days. Hence, we are offering a superior bush at lower prices with some profits in our pocket. This manufacturing cost can be further reduced by reducing the manpower cost which can be done by printing the batch of bushes in single go. Filament prices can also be lowered if purchased in bulk which can further increase annualized profit.

14.0 CONCLUSIONS

In this report, we have obtained different values for various mechanical properties like hardness, tensile strength, compressive strength and izod impact. These values for originally injection molded ABS bush and 3D printed PC bush has been compared. These values might not have big difference if we have used same ABS material for 3D printing also. Hence, PC material for 3D printing of bush was used. The final obtained product has considerable higher mechanical properties than already available bush in market which leads to higher life cycle of these bushes. Total manufacturing cost of 3D printed PC bush was also lower than the import cost of bush which can further reduced by printing the bushes in batches and purchasing the filaments in bulk. Also, traditional methods like injection molding requires high fixed cost of machinery with a dedicated die which cost around 25000/-. It takes some months to cover the cost of die itself. Also, if demand is lower than production has to be paused for that duration die remains idle but FDM setup can be utilized for variety of product simultaneously. Hence, FDM gives you advantage of zero idleness of machine and one can be profitable from the day one. Additive manufacturing enables localized production that creates competition in market. It also reduces the dependency over monopolists. Hence, AM technology reduces the selling cost of products which are selling at substantially higher prices due to lesser competition in market that directly benefits the consumer and society.

ACKNOWLEDGEMENT

I express my profound sense of gratitude to Mr. Rajhans Meena who allowed me to 3d print bushes and various samples in 3D printing lab at MNIT, Jaipur. Testing of obtained samples was also arranged by him at his college facility. I also express my gratitude and deep respect to Dr. Kailash Choudhary who guided me from start to end of this research at MBM University Jodhpur.

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