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Research article

Fabrication of 3D-Printer & Design Optimization of 3D Printed Parts for Digital Manufacturing

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Abstract

This paper outlined the procedural steps involved in the construction of a three-dimensional (3D) printer, as well as the techniques used to enhance the design efficiency of components produced via 3D printing for digital manufacturing. The study aims to enhance the quality and efficiency of 3D printing technology for industrial applications. Digital manufacturing is a term that encompasses a wide range of technologies and processes that use digital technologies to design, create, and print physical 3D products. We are fabricating a 3D printer and 3D-printing different products to assess their strength like UTS. Subtractive manufacturing causes raw material wastage. On the other hand Digital manufacturing is based on additive manufacturing which allows us to manufacture products without tooling and to consolidate assemblies into a single part with minimal wastage of material .3Dprinter makes easy manufacturing of all types of components widely found in aerospace, automobile, and medical fields. FEA analysis is performed on the same designed parts manufactured by the different 3D printers. Finite Element Analysis (FEA) is a computational technique that facilitates the simulation of physical processes. By using FEA, the need for physical prototypes may be minimized, enabling the optimization of components within the design phase of a project. Topology optimization will be performed which will help us to find the best distribution of the material in our desired product. Comparative analysis is performed to identify any deviations or defects in the 3D-printed part. The fabrication of a three-dimensional (3D) printer and the enhancement of components produced via 3D printing are paramount in the additive manufacturing procedure. By reducing weight and conducting a comparative analysis, Digital manufacturing can produce parts with high precision and accuracy, contributing to the growth and development of various industries

Keywords: 3D Printer, Digital Manufacturing, FEA Analysis, Topology Optimization, 3D printing & FEA.

Introduction

The process of creating material layers one at a time from a digital 3D model to an actual product is known as additive manufacturing, or 3D printing. A 3D printer is used, which reads the digital design and builds the real object by layering on material one at a time until the full thing is created.

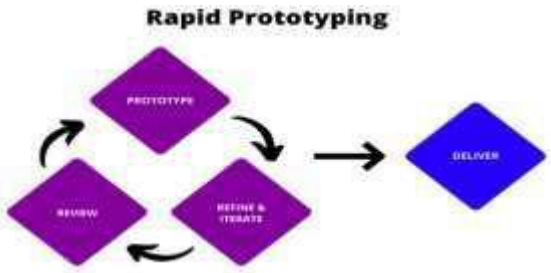
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Figure 1: Horizontal Bed 3D Printer

The origins of 3D printing can be linked to American studies in photography, sculpture, and landscape design. Up until the middle of the 1980s, most of the technology was still in its early stages. 3D printing was referred to as "RAPIDPROTOTYPING" during this time. The first practical 3D printer was created by Chuck Hull of 3D Systems Corporation. During the beginning of a study being carried out by the Defense Advanced Research Projects Agency, Dr. Deckard at the University of Texas synthesized Selective Laser Sintering (SLS) technology. With the development of a technique that uses UV light to solidify photopolymer, an extremely viscous liquid material, the technology was further improved in the 1990s. A small number of goods were printed using very expensive 3D printers in the 20th century. Scientists and electronics enthusiasts owned the majority of the printers for use in research and display. However, developments in 3D printing have made it possible for product design to no longer be constrained by intricate designs or vibrant colors. Our 3D printer can be useful in various industries and fields, including manufacturing, healthcare, architecture, fashion, education, and research. Some of the key reasons why 3D printers are considered necessary and significant are

Rapid product prototype made possible by 3D printing can cut the time and cost associated with product development. Thus, our Project enables businesses to swiftly test their concepts and make changes, resulting in quicker product development and speed to market [2].



Customization

Our 3D printer enables product customization depending on particular needs, including unique body shapes for prosthesis or individualized products for customers. It was impossible to achieve this level of personalization using conventional production techniques [3].

Increased efficiency

Due to the ability to produce intricate parts and geometries in a single step using 3D printing, production time and costs can be greatly decreased. Hence, the possibility that our project may boost production and efficiency across numerous industries [8].

Improved quality

3D Printer allows for the production of high-quality and precise parts, which can meet the strict requirements of industries such as aerospace and healthcare.

Cost-effectiveness

3D printing can be more cost-effective than traditional manufacturing methods, especially for low volume production. Our project is an attractive option for small businesses and startups.

Innovation

3D printing has opened up new avenues for innovation in various fields, such as healthcare, where it is used for the production of personalized implants and prosthetics, and fashion, where it is used for the production of unique designs [5].

Aim and Objective

Fabrication

Our project's research primary goal was to build a 3D printer on our own at a price that would be less expensive than that of commercial printers, and then utilize it to optimize the design of 3D printed parts for digital manufacturing. This entails making sure the printer can manufacture high-quality parts and that the optimized designs can be produced through digital manufacturing dependably and effectively [5].

FEA Analysis

After manufacturing, we used ABS and PLA to print various hooks. ABS stands for acrylonitrile butadiene styrene. Parts that were printed underwent FEA analysis. Through topology optimization, FEA analysis is a useful tool for improving the design of 3D printed objects. By using FEA analysis, 3D printed parts can be made to be structurally [2] sound and compliant with standards



Figure 2: Finite Element Analysis Model

Sustainability of Project

Resource efficiency

The amount of material required for 3D printed items can be greatly decreased while preserving their structural integrity thanks to the topology optimization technique utilized in this research. This enhances resource efficiency and reduces material waste.

Energy efficiency

Since it requires less energy to make parts, 3D printing technology is typically seen as being more energy efficient than conventional manufacturing procedures. Energy usage can be further decreased by using topology optimization to cut the amount of material [24] utilized in 3D printed items.

Reduced carbon footprint

The initiative can aid in lowering the carbon footprint connected to the production of mechanical parts by minimizing material waste and energy use. This advances general sustainability objectives.

Circular economy

The ability to produce parts on demand using 3D printing technology eliminates the need for extensive manufacturing runs and reduces inventory. Reduced waste and promoted [3] resource efficiency help to support the tenets of the circular economy.

Local production

Localized production is made possible by 3D printing technology, which eliminates the need for international product shipping. This can boost regional economies while lowering emissions associated to transportation [7].

Literature Review

The beginning of 3D printing is related to studies of photography, sculpting, and Landscape design, which took place in America. Much of the technology was not being developed until the mid-1980s. During this period, 3D printing was known as RAPIDPROTOTYPING". Chuck Hull, of 3D Systems Corporation, manufactured the first usable 3D printer. Later in the 80's, Selective Laser Sintering (SLS) technology was synthesized by Dr. Deckard at the University of Texas during the commencement of project being done by Defense Advanced Research Projects Agency. In the 1990s, the technology was further improvised with the advancement of a method that uses UV light to solidify photopolymer, a highly viscous liquid material. In the 20th century, 3D printers were very expensive and were used to print a few numbers of products. Most of the printers were owned by scientists and electronics groupies for research and display. However advancements in the area of 3D printing have allowed for the design of products to no longer be limited by complex shapes or colors.

Printing Methods

Wax, nylon, and thermoplastics like ABS (Acrylonitrile Butadiene Styrene) were all used in this procedure. The first step in the FDM process is to warm up the thermoplastic component until it is in a tangled state. The 3D printer then builds the 3D item layer by layer using advanced demonstrating information from a CAD record. The printers combine a significantly weaker support composite. The Supporting material serves as the test item's framework. When building components with overhangs that can't support it, this is helpful. Most thermoplastics have a filamentous structure that facilitates heat transfer and allows them to move with a print head that moves in the x and y directions. A cylinder moves across the stage at the separation of printed layer thickness (z-hub) after each layer has been printed.

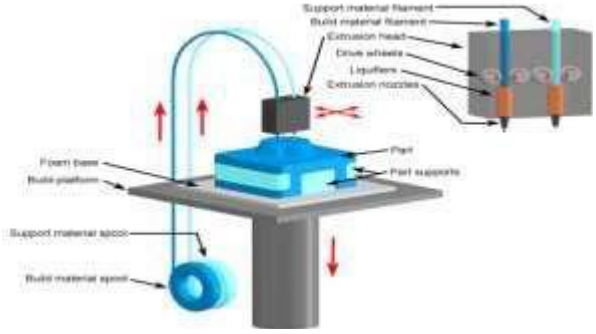


Figure 3: PLA Printing (Photo credit BMI Lab)

Material Used

Polylactic Acid: One of the most popular plastics in the field of additive manufacturing is PLA (polylactic acid). This substance, developed in 1930 by chemist Wallace Carothers, who also created nylon and neoprene, can be utilized in pellet or filament form for desktop 3D printers or other commercial applications. Contrary to many other material options on the market, PLA is frequently seen as a more environmentally friendly thermoplastic because it is derived from natural and renewable resources rather than finite resources like petroleum. This substance has gained popularity in the 3D printing industry since the beginning because of its relatively more environmentally friendly beginnings. In reality, a vast range of industries and applications now depend on it.

Acrylonitrile Butadiene Styrene (ABS): Acrylonitrile Butadiene Styrene, also known as ABS, is a thermoplastic polymer that is frequently used in industrial settings. It is particularly renowned for producing lightweight parts and having a good impact resistance at low temperatures. As one of the most extensively utilized materials in this industry, along with PLA, ABS plastic is also quite well known in the 3D printing market. Although it is most frequently used in FFF 3D printing, it is also accessible in resin form, enabling its usage in vat polymerization techniques. In the following article, we'll explore in more detail at ABS, including its manufacturing process, features, uses, major manufacturers, and cost. We'll pay close attention to ABS filaments in particular.



Figure 4: ABS Material (Photo credit BMI Lab)

Finding and Discussion

To determine the mechanical properties of the material we made a test on UTM (Universal Testing Machine). The test involves subjecting a specimen to controlled forces and measuring its response to those forces, including properties such as tensile strength, compressive strength, and elasticity.

Universal Testing Machine (UTM) test

UTM stands for Universal Testing Machine and is used to determine the mechanical properties of materials. Among the properties typically measured are tensile strength, compressive strength, and elasticity. Below are the steps for performing the test:

1. The specimen was prepared at first using ABS and PLA material.
2. Install the hook-shaped samples onto the UTM machine in accordance with the manufacturer's instructions. Set the necessary test parameters, including the load and displacement ranges.
3. Start the UTM machine and apply either tension to the hook-shaped specimens. The specimens are subjected to increasing levels of stress until they reach their maximum stress limit.
4. Using the load and displacement data, calculate the mechanical properties of the PLA and ABS materials, such as tensile strength, compressive strength, and modulus of elasticity [**15**].

PLA hook's results



Figure 5: PLA Original Hook



Figure 6: PLA Deformed Hook

When the hook made from PLA was subjected to stress on the Universal Testing Machine (UTM), the applied load gradually increased until the hook could no longer withstand it and fractured. The force at which the hook fractured, **19.34Kg**, is known as the hook's breaking strength. This indicates that the hook could withstand forces up to 19.34Kg, but any additional force caused it to fracture. The breaking strength of the hook is a crucial mechanical property that determines how much force the hook can withstand before breaking.

PLA Optimized Hook's Results



Figure 7: PLA Optimized Original Hook



Figure 8: PLA Optimized Deformed Hook

The force at which the optimized hook fractured was 19.09 kg. The PLA-optimized hook's breaking strength is 5% lower than the PLA-made hook's breaking strength of 19.34 kg. This indicates that the optimization procedure for PLA may have had a negative impact on the material's mechanical properties, such as its strength or toughness. The mass of PLA optimized Hook is **5 %** less than PLA hook.

ABS hook's results



Figure 9: ABS original Hook



Figure 10: ABS Deformed Hook

When the ABS hook was subjected to stress on the Universal Testing Machine (UTM), it experienced a gradual increase in force until it reached a point where it could no longer withstand the applied force and fractured. 19,97 kg was the breaking force of the hook. The ABS hook has greater breaking strength than the PLA hook and the PLA-optimized PLA hook. This indicates that the ABS material has greater mechanical properties, including strength and durability, compared to the PLA material.

Comparison

The PLA-made hook broke at 19,34 kg, whereas the PLA-optimized hook broke at 19,09 kg. Particularly, the total weight of the optimized PLA hook is 5% less than that of the standard PLA hook. This indicates that the optimized PLA hook is less strong than the standard PLA hook. The ABS hook broke at 19.97 kg, which is slightly more than both the PLA and PLA-optimized hooks.
This indicates that ABS possesses higher tensile strength than PLA and PLA-optimized. The Comparison between PLA Hook, PLA optimized Hook and ABS Hook is as follows.

HOOKS	Deformation (mm)	Failure Load (Kg)	Picture of Failure
PLA Hook	0.0413 mm	19.34 kg	
PLA Optimized Hook	0.0402 mm	19.09 kg	
ABS Hook	0.0598 mm	19.97 Kg	

Table 1: Comparison of UTS results

Conclusion

In conclusion, this thesis has presented the fabrication of a 3D printer and the design optimization of 3D printed parts for digital manufacturing. The development of the 3D printer involved selecting appropriate components and assembling them to form a functional printer. The printer was then calibrated and tested to ensure its accuracy and reliability in producing quality prints. Design optimization of 3D printed parts was also explored, focusing on the use of software tools to improve part performance and reduce production time. Various design parameters such as infill density, layer thickness, and print orientation were analyzed to determine their effect on part quality and strength. The results showed that optimizing these parameters can significantly enhance the performance of 3D printed parts. Overall, the work presented in this thesis provides valuable insights into the fabrication of 3D printers and the design optimization of 3D printed parts for digital manufacturing. The knowledge gained from this study can be applied in various industries, including aerospace, medical, and automotive, where 3D printing technology is increasingly being adopted. Further research can build on this work to explore new techniques and methods that can further enhance the capabilities of 3D printing technology.

United Nations Sustainable Development Goals (SDGs)

For your final year project on a 3D printer, you can align it with the United Nations Sustainable Development Goals (SDGs) by focusing on the following areas:

SDG 9: Industry, Innovation, and Infrastructure:

Ongoing innovation in 3D printing technology offers opportunities for sustainable manufacturing and infrastructure development. Efficient resource use, waste reduction, and sustainable materials drive progress in 3D printing, paving the way for future advancements and empowering young engineers for innovation. Industry and research institutes are actively building infrastructure to support these efforts

SDG 12: Responsible Consumption and Production:

Our project develops a 3D printer that promotes sustainable production practices. It prioritizes energy efficiency, material recycling, and minimizing environmental impact during printing. By using eco-friendly materials and implementing advanced filtration systems, we aim to contribute to responsible consumption and production.

SDG 13: Climate Action:

Our project prioritizes the use of environmentally friendly materials and manufacturing processes. By selecting materials with lower carbon footprints, such as recycled or bio-based materials, we minimize the environmental impact associated with the production and assembly of the printer. Through advanced design and simulation techniques, we aim to reduce material waste by optimizing part geometries and minimizing support structures. This not only improves the overall efficiency of the printing process but also decreases material usage, leading to reduced environmental impact

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