Design and Analysis of 3d Printer Using Reinforced Natural Fiber Filament

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ABSTRACT

3D printer technology is commonly known as additive manufacturing.it is a process of creating three-dimensional (3D) object from digital model created using design software such as CAD and CREO, this digital model sliced in slicing software to generates G codes. These G codes command the printer how to move, printer speed, layer thickness and temperature of the extruder. Conventional filament like PLA and ABS are synthetic polymer pose an environmental challenge because of their non-biodegradable nature. in recent years, research have exploded the use of reinforced natural fiber filament such as jute, bamboo, hemp and flax. natural fiber obtains from animals and plant, giving sustainable biodegradable alternative to synthetic fiber. this natural fiber combines with thermoplastic polymer matrix mostly polylactic acid (PLA) with natural fibers like hemp, bamboo, flax. use of natural fiber reduces environmental impact, improve sustainability and provide unique surface aesthetic however this filament also possesses some challenges during printing such as nozzle clogging, uneven extrusion and increase wear on printing components also it reduces tensile strength, increase brittleness. Moisture sensitivity. Thermal stability of natural fiber filament is lower compare to pure polymer. It also shows the lower thermal degradation than synthetic polymers that constrains processing temperature during processing 3D printer. Current research in material science and engineering focus on developing fiber matrix compatibility through coupling agents, surface modifications, and the incorporation of nano-scale reinforcements using cellulose nanofiber It commonly used in textile and various industry. This research aims to design and analyze a 3d printer system optimized for reinforced natural fiber filament

Keyword : - *Additive Manufacturing, Natural Fiber Filament, Reinforced Composites, and Sustainability, Biodegradable Materials*

1. INTRODUCTION

3D printer technology commonly known as additive manufacturing.it is a process of creating three-dimensional object from digital model created using design software, this digital model use to generates g codes. This codes command the printer how to move, printer speed, layer thickness and temperature of extruder. Conventional filament like pla and abs are synthetic polymer pose a environmental challenges because of their non biodegradable nature, in recent years, research have explodes the use of reinforced natural fiber filament such as jute, bamboo, hemp and flax how ever this filament also possess some challenges during printing such as nozzle clogging, uneven extrusion and increase wear on printing components this research aim to design and analyze a 3d printer system optimized for reinforced natural fiber filament

1.1 Literature Review

Several research has done on natural fiber composite in additive manufacturing. in 2016 Le Duigou et al. developed a wood fiber reinforced PLA composite, they found that natural fibers improve stiffness but increased brittleness [1] . Tao et al. (2017) researched on bamboo fiber reinforced polymer composite for 3d printing, it improved environmental sustainability but required modification to nozzle diameter and extrusion temperature [2] . Kariz et al. (2018) studied on wood pla composite filaments and found that higher the fiber content in composite increased nozzle blockage risk[2] .

2. METHODOLOGY

First approach in this research is identifying problem face during 3D printing using natural reinforced fiber filament. In order to identify this problem some background research on this technology was conducted Fused deposition modeling
The concept of fdm technology was developed by S. Scott Crump in 1988.it create three-dimensional object by melting filament and extruding it through heated nozzle and depositing it layer by layer

2.1 Working Process

In this phase 3d cad model is created using cad software or with 3d scanner. The file created in this software sent to a slicing software of 3d printer which slice this model into numerous horizontal layers, determining thickness of layer based on user setting. It finds most efficient deposition path for nozzle to follow each layer and at last It generates g codes which contain for printer, include temperature stetting, feed rate, movement there are some widely used slicing software are cure, slic3r and Prusa slicer. FDM 3d printer basically work on 3 dimension which are x, y and z. this movement provided with the help of low torque and high precision motor. the most commonly used motor for 3d printer is a stepper motor, it is a brushless electric motor that rotate in small discrete steps. It operates base on electromagnetic field. It provides left right motion along x axis for nozzle, forward backward motion along y axis for heating bed, vertical motion along z axis for nozzle and in filament extrusion by feeding filament into nozzle Processing. TriGorilla Generation 4.0 motherboard is the main control board we are using.
It use marlin firmware to perform critical function like:
Executes G-code commands
Controls X, Y, Z stepper motors
Controls extruder motor
Regulates nozzle and bed temperature
Reads thermistors and endstop sensors
Controls fans and LCD display

2.2 Selection of mechanism

We select cartesian mechanism because it most widely used motion system in 3d printer it operated on Cartesian coordinate system in which movement occur along x, y and z axis. In this mechanism x axis used for horizontal movement of printer head y axis for forward and backward movement of printer head and z axis for vertical movement of printer head for layer deposition

3. ELECTRONICS

Following electronics components are used in 3d printers

i. Controller
ii. Stepper Motor
iii. Endstops
iv. Heated bed
v. Stepper Drive

3.1 Controller

It is processing unit of a 3d printer, responsible for interpreting g codes and coordinating all hardware pereion in 3D printer. We are using TriGorilla Generation 4.0 motherboard is the main control board that we are using marlin firmware in our 3D printer. It use to operate function of g code instruction, motion of stepper motor, regulate temperature, interfaces with sensors

3.2 Stepper Motor

Stepper motors are electromechanical device that convert electrical signal into mechanical movement of motor. They are use to control axis (X, Y, Z) and extrusion of 3D printer. It operate inn discrete steps that is 1.8° per step = 200 steps/revolution having torque between Holding torque: 30–60 N·cm

3.3 Endstops

It is limit switch use to provide physical boundaries to printer axis movement to ensure homing and mechanical overtravel it have 3 types basically mechanical switch, optical sensors, hall effect sensors. They send signal to controller when triggered. It use to homing process to achieve reference position of axis that is 0,0,0

3.4 Heated BED

The heated bed is a temperature control platform that ise to improve printer adhesion, reduce warping of thermoplastics such as PLA and ABS

3.5 Stepper Drive

It act as intermediate between the controller and stepper motor to regulate current and enabling accurate motion control. A4988 Stepper Motor Driver is widely used stepper drive in 3D printers. The main function of it is convert control signal Motor motion, control current to prevent heating and enable micro stepping for smoother motion by using Microstepping with full, 1/2, 1/4, 1/8, 1/16 steps, Current limiting via potentiometer, Thermal shutdown protection

4. Design Calculations for FDM 3D Printer

Build Volume and Frame Design
Assume a target build volume similar to standard 3D printers
Build volume ≈ 220 × 220 × 250 mm
Frame Sizing
To accommodate motion and components:
Frame size (X, Y)= Build are + 2(belt clearance + carriage width)
Typical assumption:
Clearance = 40–60 mm

Frame size≈220+2(50)=320mm
Final frame ≈ **320 × 320 × 350 mm**

4.1 Stepper Motor Torque Calculation
Using a **NEMA 17 Stepper Motor**
Force Requirement:
F=m·a
Where:
m = moving mass (≈ 1.5 kg for bed or gantry)
a = acceleration (≈ 1000 mm/s² = 1 m/s²)
F=1.5×1=1.5N
Torque Calculation:
T=F·r /η
Where:
r = pulley radius ≈ 10 mm = 0.01 m
η = efficiency ≈ 0.8
T=1.5*0.01 /0.8 = 0.01875Nm
Required torque ≈ **0.02 Nm**
NEMA 17 provides **0.4–0.5 Nm = Safe margin**

4.2 Belt Drive Calculation (X/Y Axis)

Belt Type:
GT2 belt (pitch = 2 mm)
Steps per mm:
Steps/mm= Motor steps]×Microstepping / Pulley teeth×belt pitch
Assume:
Motor = 200 steps/rev
Microstepping = 16
Pulley = 20 teeth
Steps/mm=20×16 / 20×2=80steps/mm

4.3 Lead Screw Calculation (Z-Axis)

Using T8 lead screw:
Pitch = 2 mm
Starts = 4 → Lead = 8 mm/rev
Steps/mm=200×16 / 8 = 400steps/mm

4.4 Heated Bed Power Calculation

Typical bed size: 220 × 220 mm
Power Requirement:
P=V×I
Assume:
Voltage = 24V
Current = 10A
P=24×10=240W
Heat Energy:

$Q = mc\Delta T$
Where:
m = 0.8 kg (aluminum bed)
c = 900 J/kg·K
ΔT = 60°C
$Q = 0.8 \times 900 \times 60 = 43{,}200 J$
$t = Q/P = 43200/240 = 180 sec \approx 3 min$

4.5 Extrusion Flow Rate

Volumetric Flow Rate:
$Q = A \cdot v$
Where:
Nozzle diameter = 0.4 mm
Layer height = 0.2 mm
Print speed = 100 mm/s
$A = 0.4 \times 0.2 = 0.08 mm^2$
$Q = 0.08 \times 100 = 8\ mm^3/s$
PLA limit: **8–12 mm^3/s**

5. CONCLUSIONS

This project demonstrate that reinforced natural fiber filament offers sustainable alternative to synthesis material in FDM 3D printing. They improve environmental performance and aesthetics but they introduce challenges such as nozzle clogging, reduce strength, and some thermal limitation, the motive of this project is optimizing parameter and components of 3d printer to effectively address these issues. Overall natural fiber composite demonstrates strong potential for eco-friendly additive manufacturing, with further improvements needed in material properties and printing reliability.

6. REFERENCES

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