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Optimization and dimensional accuracy analysis using Genetic Algorithm of polymeric biocomposite parts fabricated by Fused filament fabrication

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Abstract: Fused Filament Fabrication (FFF) uses semi molten beads of thermoplastic-based polymeric bio-composite materials which are deposited by numeric controlled nozzle on heated bed. The polymeric bio-composite predicated parts made through this disruptive technology were initially used for prototyping but now-a-days used for direct applications also. The three dimensional motion of heated bed and nozzle facilitates the easy fabrication of polymeric bio-composite parts based on CAD data. There are numerous input parameters of FFF which influence the surface finish, dimensional accuracy, mechanical strength and aesthetic value of finished products. The dimensional accuracy of FFF parts is very critical if these polymeric bio-composite parts are used for aerospace, automobile, biomedical and electronics applications. Thus, present study has been carried out for optimization of process parameters of FFF and prediction of best value of dimensional accuracy of for polymeric bio-composites using Genetic Algorithm. The output dimensions in the form of length, width, diameter and thickness of benchmark have been considered. The input parameters used in present analysis are layer thickness, raster angle raster width, air gap and orientation angle with three levels of each. The output of prediction tools of Genetic Algorithm was validated with 99.71% accuracy and it was found that advanced optimization technique yielded positive results as compared to traditional optimization techniques.

Keywords: Fused Filament Fabrication, Dimensional Accuracy, Genetic Algorithm, Additive Manufacturing, Optimization, Prediction

1. Introduction

Additive Manufacturing technology has brought a paradigm shift in scenario of production and manufacturing units by bringing advanced processes which significantly reduced the time and cost [1, 2]. The one of most significant advantage if these technologies is fabrication of customized products directly from computer generated designs. This eliminated the need of jig, fixtures, costly tooling and use of coolants as compared to subtractive manufacturing techniques [3-5].

The process flow chart and different stages of fabrication through FFF are depicted by figure 1.

The FDM machine program analyzes the geometry and generates suitable toolpath for fabrication [6-7]. Depending on toolpath, the warmed nozzle head moves in Y and X direction whereas semi molten plastic bead is actually extruded and ultra thin layers got precisely settled on base [8-9]. The material solidifies immediately and nozzle head is actually raised numerically in Z direction distant relative to table to deposit subsequent layers [10-11]. The FDM has potential to use a variety of build materials, many levels of ABS, nylon and composites based upon type of application [twelve, thirteen]. The support material is actually extruded through many other nozzles acting as scaffolding that is water soluble and afterwards removed from substrate [14-16]. The support structure burrs are actually eliminated possibly by hand or even using ultrasonic vibrations or perhaps may be just dissolved into sodium hydroxide solution [17-25]. The FDM parts likewise need post processing to boost surface finish as specific surface irregularities are actually generated because of two layer by layer manufacturing [nineteen, twenty]. You will find different post processing methods out there based upon specific requirement [21-24, 26-57].

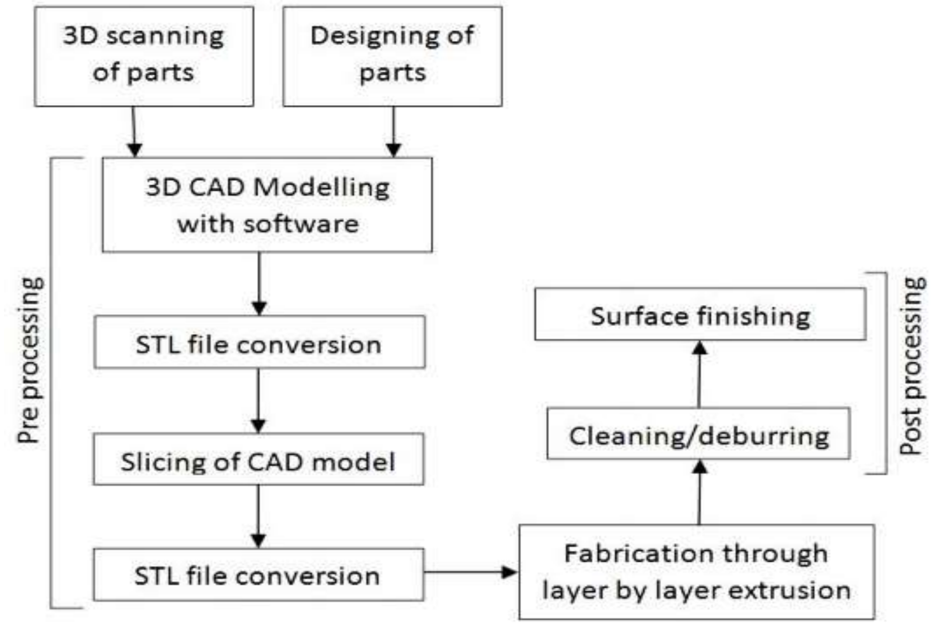

Figure 1 Methodology and different stages of FFF process

The working and major components of FFF apparatus has been shown in figure 2.

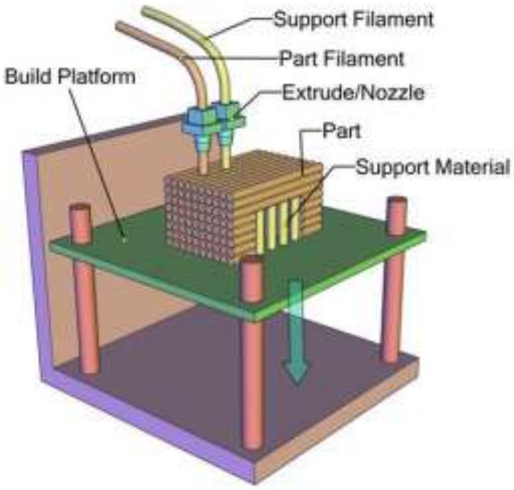

Figure 2 Schematic and major components of FFF apparatus

2. Experimentation

The fabrication of benchmark components of structural polymeric composites has been carried out at different input parameters and levels which has been shown in Table 1.

Table 1 Input Parameters of FFF

S No	Symbol	Parameter	Lower Value	Middle Value	Upper value
1.	A	Layer thickness (mm)	0.127	0.178	0.254
2.	B	Orientation Angle (degrees)	0	15	30
3.	C	Raster Angle (degrees)	0	30	60
4.	D	Raster Width (mm)	0.4064	0.4564	0.5064
5.	F	Air Gap (mm)	0	0.004	0.008

The equation generated by calculation of Mod L with 70% importance to length and 10% importance to each width, diameter and thickness is given as:

$$\begin{aligned} Mod\ L = {} & -0.93 - 3.20\,A + 0.0174\,B - 0.00350\,C + 7.9\,D - 14.0\,E + 37.62\,A*A - 0.000665\,B*B \\ & - 0.000050\,C*C - 7.7\,D*D + 156\,E*E - 0.0210\,A*B - 0.0309\,A*C - 13.7\,A*D - 55\,A*E \\ & - 0.000026\,B*C + 0.0196\,B*D + 0.429\,B*E + 0.0239\,C*D + 0.326\,C*E \end{aligned}$$

Here Modified Length L is calculated by multiplying output by percentage weightage as:

$$Mod\ L = 0.7\Delta L + 0.1\Delta W + 0.1\Delta T + 0.1\Delta D$$

The change in length, width, thickness and diameter is measured as difference between initial and final dimension and the target function is minimization of dimensional variation.

3. Results and Discussions

Five independent variables and one response parameter is considered in this research work to develop the algorithm. The 70% data set is used for training of model only and rest of data set is divided equally in testing and validation. The regression model fit for training and for all (i.e training, testing and validation) is computed. The validation performance of algorithm is also computed using data set. It has been observed that validation of network can be maximized using large number of data set. Hence twenty-seven experiments were conducted and dimensions were measured before and after which led to generation of large dataset.

The Genetic Algorithm tool has been used to analyse the impact of each input parameter on dimensional accuracy of FFF parts. The training results are shown in figure 3.

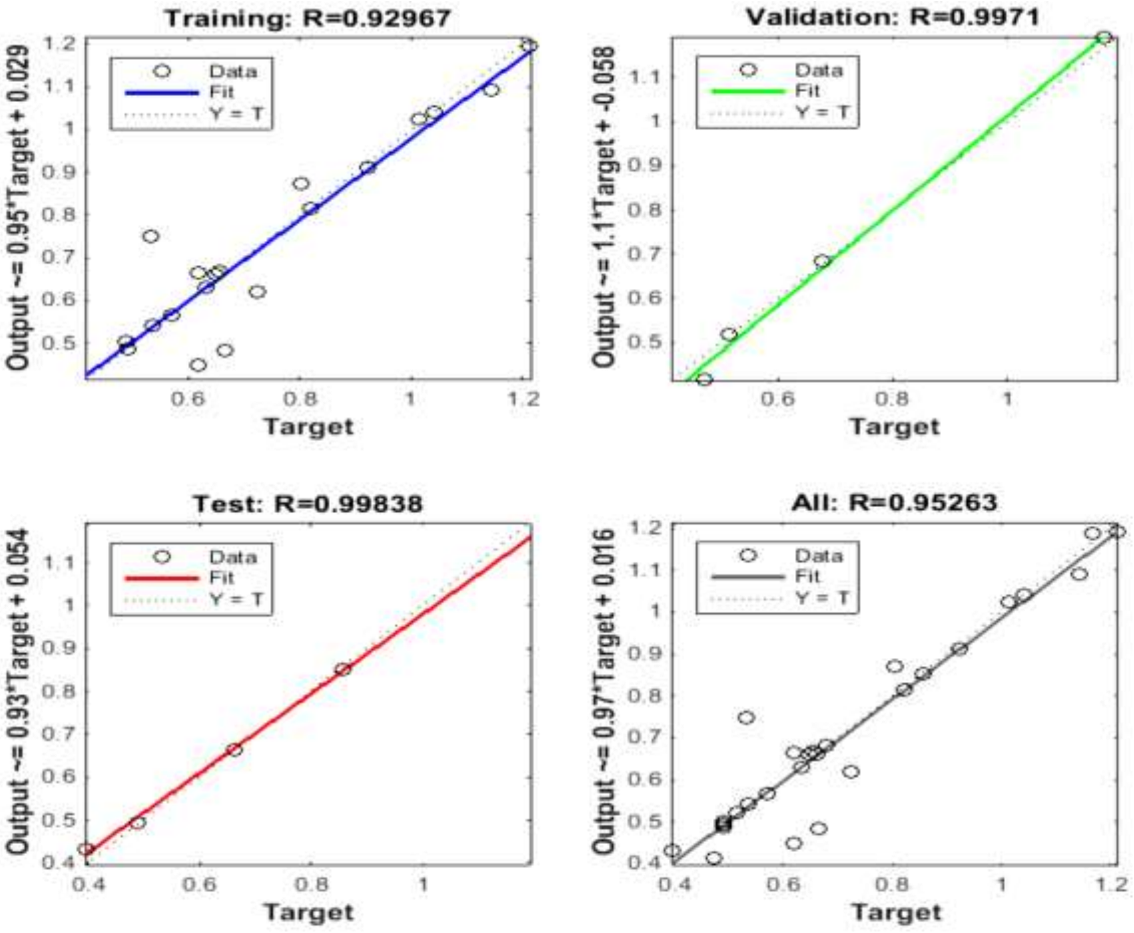

Figure 3 Training, validation and test graphs produced by Genetic Algorithm

The data generated for gradients through advanced optimization tool has been shown in figure 4.

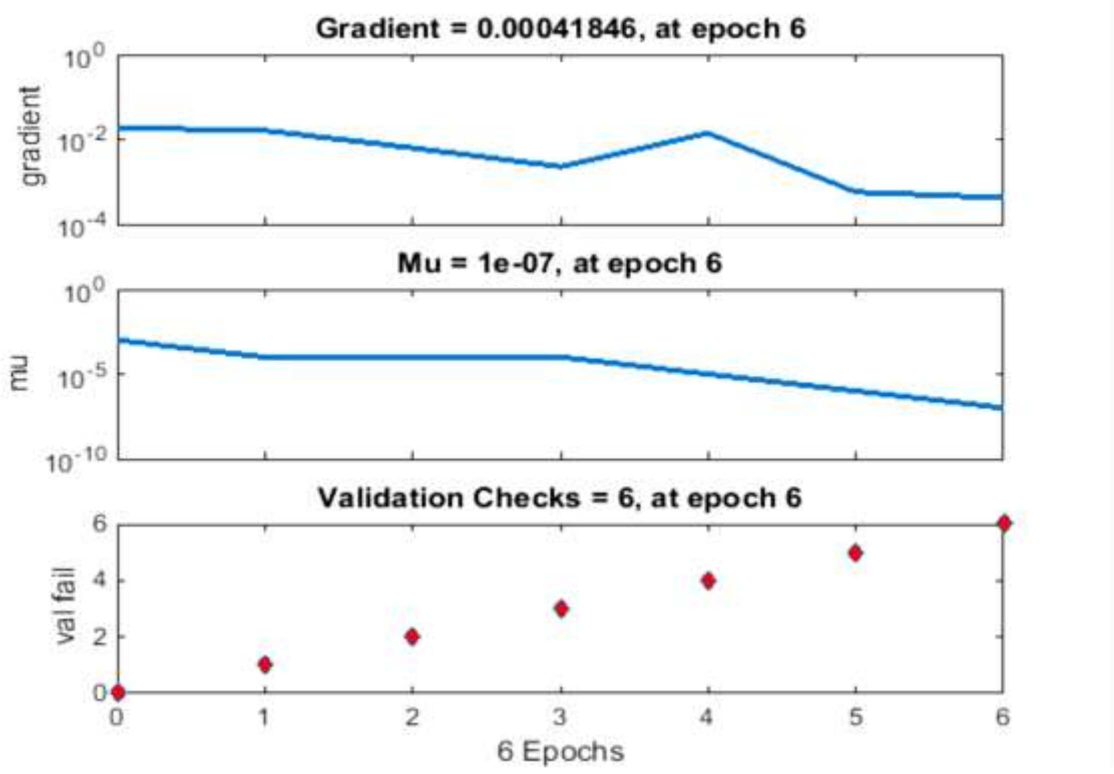

Figure 4 Gradient and validation results

The results depicted in figure 5 are derived from Genetic Algorithm interface during prediction and analysis at different values of epoch.

The data for measured and predicted values of Mod L along with error are shown in Table 2.

Table 2 Predicted and Measured values of dimensional accuracy

S. No.	**Measured Dimension** Mod L=0.7ΔL + 0.1ΔW + 0.1ΔT + 0.1ΔD	**Predicted Dimension** Mod L=0.7ΔL + 0.1ΔW + 0.1ΔT + 0.1ΔD	**Error**
1.	0.490957	0.487866	0.003091
2.	0.618392	0.448933	0.169459
3.	0.515515	0.520488	-0.00497
4.	0.472827	0.414629	0.058198
5.	0.666024	0.483883	0.182141
6.	0.532596	0.749542	-0.21695
7.	0.488827	0.494557	-0.00573
8.	0.661889	0.662555	-0.00067
9.	0.619435	0.663724	-0.04429
10.	0.394568	0.431557	-0.03699
11.	0.632302	0.630593	0.001709
12.	0.648102	0.661379	-0.01328
13.	0.569976	0.566677	0.003299
14.	0.724191	0.618525	0.105666
15.	0.678546	0.682829	-0.00428
16.	0.489009	0.501877	-0.01287
17.	0.654945	0.669085	-0.01414

18.	0.535809	0.541292	-0.00548
19.	0.820293	0.816201	0.004092
20.	1.143959	1.091357	0.052602
21.	1.168976	1.189613	-0.02064
22.	1.013522	1.023195	-0.00967
23.	1.214518	1.192317	0.022201
24.	0.855855	0.852031	0.003824
25.	0.803191	0.871134	-0.06794
26.	1.040608	1.040912	-0.0003
27.	0.923651	0.911583	0.012068

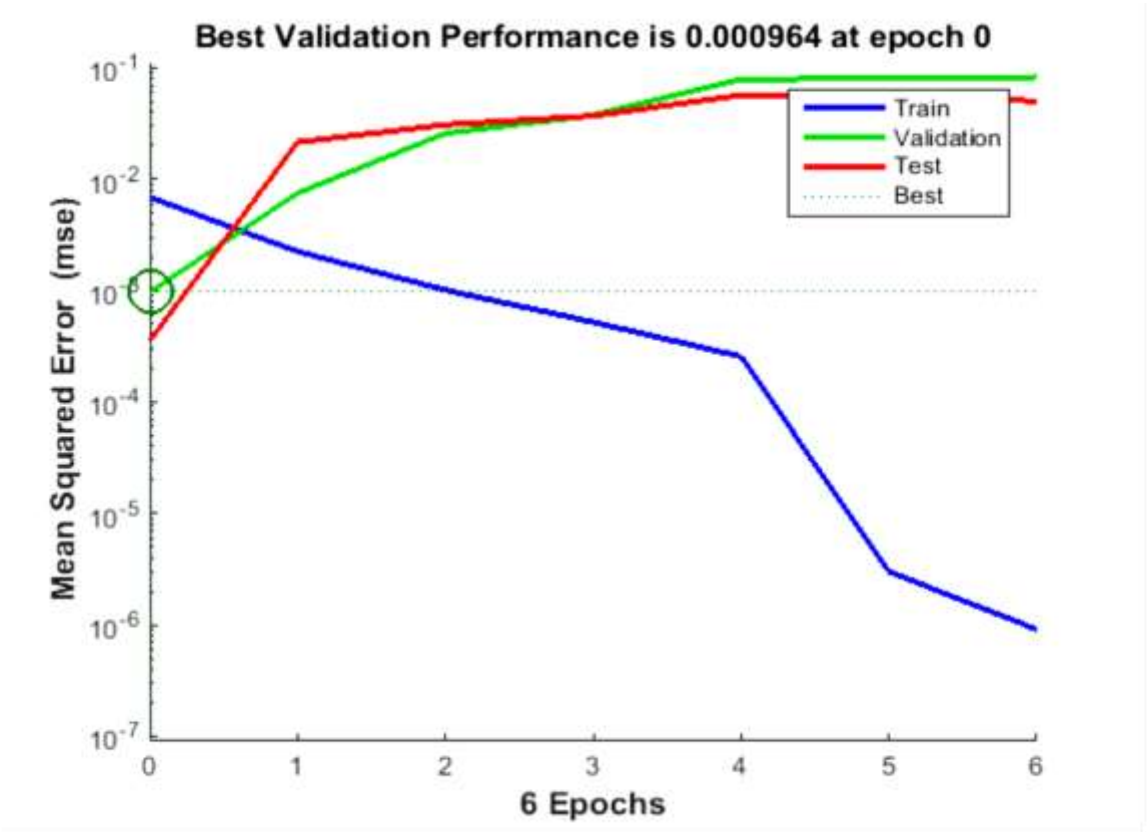

Figure 5 Mean squared error at different epochs

The results yielded by advanced optimization technique have validated it efficacy and it was found that Genetic Algorithm can be used for solving complex problems related to Additive Manufacturing.

4. Conclusions

The prediction and optimization analysis has been executed using genetic Algorithm for attaining minimum dimensional variability in for polymeric bio-composite parts fabricated through Fused Filament Fabrication (FFF). The four variables of dimensions are measures such as length, width, diameter and thickness has been measured and used as response in present study. Moreover, the weightage for each dimension is different as maximum importance is given to length (70%) while equal weightage of 10% is given to width, thickness and diameter. Total 27 different combinations of input parameters of FFF process are tested and validated using Genetic Algorithm. The recommended parametric settings were 0.1405, 0.0000, 0.0000, 0.5064, 0.0080 for layer thickness, orientation angle, raster angle, raster width and air gap respectively with objective function value of 0.2504. A small variation was observed between experimental and predicted results. The advanced optimization and prediction tool used for optimization has efficiently examined the process parameters of FFF and helped to attain minimum dimensional variability of FFF-derived polymeric bio-composite parts for structural-applications.

Conflicts of Interest:

The authors declare no conflict of interest.

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