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Investigations of process parameters of Plastic Jet Printing of polymeric biocomposites using Genetic Algorithm

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Abstract: Plastic Jet Printing (PJP) has revolutionized the digital fabrication of plastic part through low cost 3d printers for domestic and research purposes in addition to end use applications. The dimensional accuracy and surface finish of polymeric biocomposite parts fabricated by PJP is not up to industrial standards due to inherent defects and machine limitations. However, the impact of these defects can be reduced to minimum by strategically planning and executing the process at optimum process parameters. The present study has been conducted to optimize and predict the parameters of PJP to attain minimum dimensional variability in length, width, thickness and diameters of polymeric biocomposite test specimens. Genetic Algorithm has been utilized for analysis and prediction purpose which forecasts the maximum accuracy. The optimum parametric settings for layer thickness, orientation angle, raster angle, raster width and air gap has been predicted with validation accuracy of 99.30%. Also, the mean squared of error of training and validation data was minimum at suggested parameters.

Keywords: Plastic Jet Printing, polymeric biocomposite**,** optimization, Prediction, Dimensional Accuracy, Validation

1. Introduction

3d printing has overtaken the traditional manufacturing techniques due to flexible and digitized fabrication facilities which reduce gap between product conceptualization and development stages [1, 2]. There are more than 30 types of distinct 3d printing of Additive Manufacturing techniques which are utilized by manufacturers but the broad classification divides the technologies into four categories i.e. photo polymerization, materials extrusion, powder based and lamination [3-5]. Figure 1 depicts the detailed classification of 3d printing techniques.

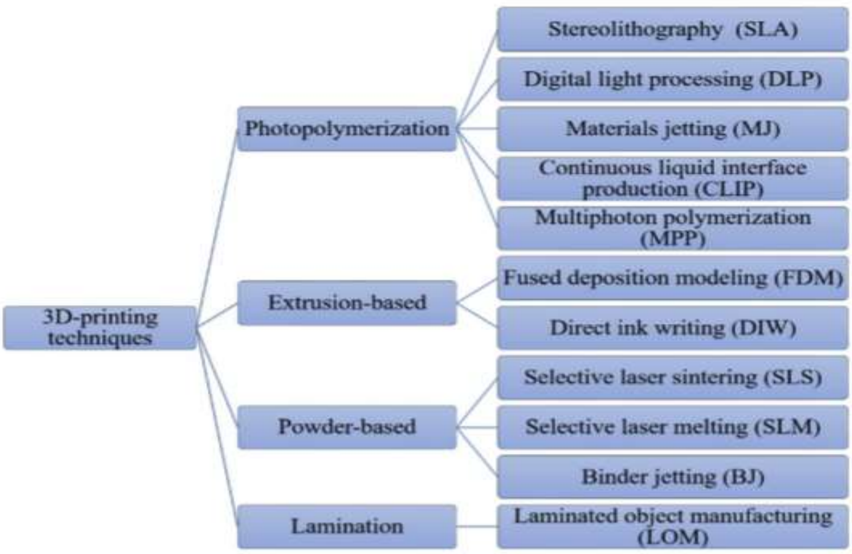

Figure 1 Classification of 3d printing techniques

Plastic Jet Printing (PJP) has replaced the traditional plastic manufacturing techniques due to low cost availability of 3d printed and raw materials [6-8]. The commercial and industrial use of PJP parts is however limited due to certain process limitations such as dimensional accuracy and surface finish of plastic parts [9, 10].

The working and basic components of PJP are shown in figure 2. In FDM, initially, the part is designed in suitable designing software and transformed to STL format for further processing [11-14]. Afterwards, toolpaths are generated by slicing software which tessellated he part into small slices instead of complex structure [15, 16]. These toolpaths drive stepper motors in pre-defined path which are further connected to extruder head [17-19]. The extruder head comprises of rollers and heated nozzle where plastic filament of build is supplied and deposited on build platform [20]. The build material in form of thin wire is heated to a temperature slightly below the melting point so that semi-molten bead is precisely layered on platform. The extruder head moves in X and Y direction while table moves in Z direction which results in 3-dimensional deposition of semi-molten plastic filament [21, 22]. In addition of part material, support material is also extruded by another nozzle to provide strength to over-hanging parts [23-36]. The support material is water soluble. The polymeric biocomposite part is ready within few hours and ready to use after removal of support structures. Now-a-days, commercial FDM machines have provision to alter different process parameters to achieve desired characteristics in final parts [25, 37-49].

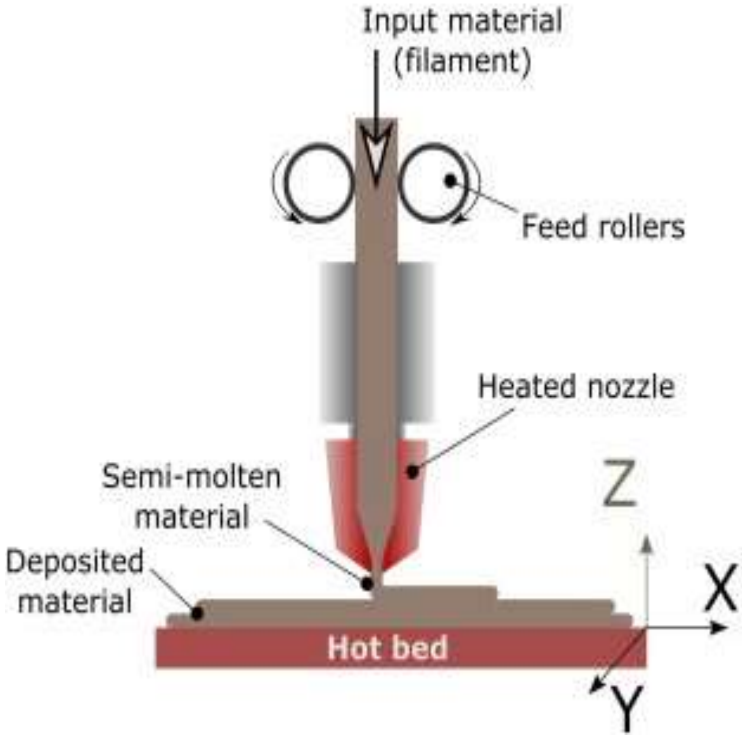

Figure 2 Schematic of PJP apparatus

2. Experimentation:

2.1. Methods:

The polymeric biocomposite test specimens were prepared at different processing conditions using PJP printer. The dimensions of parts were measured after fabrication and compared with CAD data used for printing. The difference in measured dimensions and CAD data was used to calculate the dimensional changes in width W, length L, diameter D and thickness T of specimens. Afterwards, the individual weightage of each dimension was used to generates single equation. The maximum importance was given to diameter of specimen with 70% weightage while 10% of equal weightage was given to thickness, length and width. The Mod D was calculated as:

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

Afterwards, the relationship between input parameters and response was converted into single equation using regression analysis and written as:

$$\begin{aligned} Mod\ D = & -1.39 - 0.32\,A + 0.0152\,B - 0.00761\,C + 11.2\,D - 16.7\,E + 35.56\,A*A - 0.000616\,B*B \\ & - 0.000024\,C*C - 10.3\,D*D - 46\,E*E - 0.0170\,A*B - 0.0242\,A*C - 18.6\,A*D - 29\,A*E \\ & - 0.000013\,B*C + 0.0170\,B*D + 0.347\,B*E + 0.0268\,C*D + 0.303\,C*E \end{aligned}$$

The equation has been generated using data from Table 1 which shows individual value of each input parameter.

Table 1 Input parameters and their levels along with Mod D

	Input Parameters					Response
Exp. No	**Layer Thickness (mm) A**	**Orientation Angle (°) B**	**Raster Angle (°) C**	**Raster width (mm) D**	**Air Gap (mm) E**	**Mod D=0.7ΔD + 0.1ΔL + 0.1ΔW + 0.1ΔT**
1	0.127	0	0	0.4064	0	1.050679
2	0.127	15	0	0.4564	0.004	1.142726
3	0.127	30	0	0.5064	0.008	1.046626
4	0.127	0	30	0.4564	0.004	1.037772
5	0.127	15	30	0.5064	0.008	1.146191
6	0.127	30	30	0.4064	0	1.020151
7	0.127	0	60	0.5064	0.008	1.065772
8	0.127	15	60	0.4064	0	1.173222
9	0.127	30	60	0.4564	0.004	1.142047
10	0.178	0	0	0.4564	0.008	0.981957
11	0.178	15	0	0.5064	0	1.206135
12	0.178	30	0	0.4064	0.004	1.200713
13	0.178	0	30	0.5064	0	1.105809
14	0.178	15	30	0.4064	0.004	1.233357
15	0.178	30	30	0.4564	0.008	1.193824
16	0.178	0	60	0.4064	0.004	1.039065
17	0.178	15	60	0.4564	0.008	1.194611
18	0.178	30	60	0.5064	0	1.102642
19	0.254	0	0	0.5064	0.004	1.376071
20	0.254	15	0	0.4064	0.008	1.701737
21	0.254	30	0	0.4564	0	1.672809
22	0.254	0	30	0.4064	0.008	1.586633
23	0.254	15	30	0.4564	0	1.78963
24	0.254	30	30	0.5064	0.004	1.376966
25	0.254	0	60	0.4564	0	1.384358
26	0.254	15	60	0.5064	0.004	1.602274
27	0.254	30	60	0.4064	0.008	1.50154

3. Results and Discussions

The results in form of graphs and tables were derived using Genetic Algorithm technique which identified optimum parameters and also validated the selected parameters. Five independent variables and one response parameter is considered in this research work to develop 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 graphical description of training, regression, test and overall characteristics has been shown in Figure 3 which indicates that 99,30% accuracy has been achieved in overall analysis.

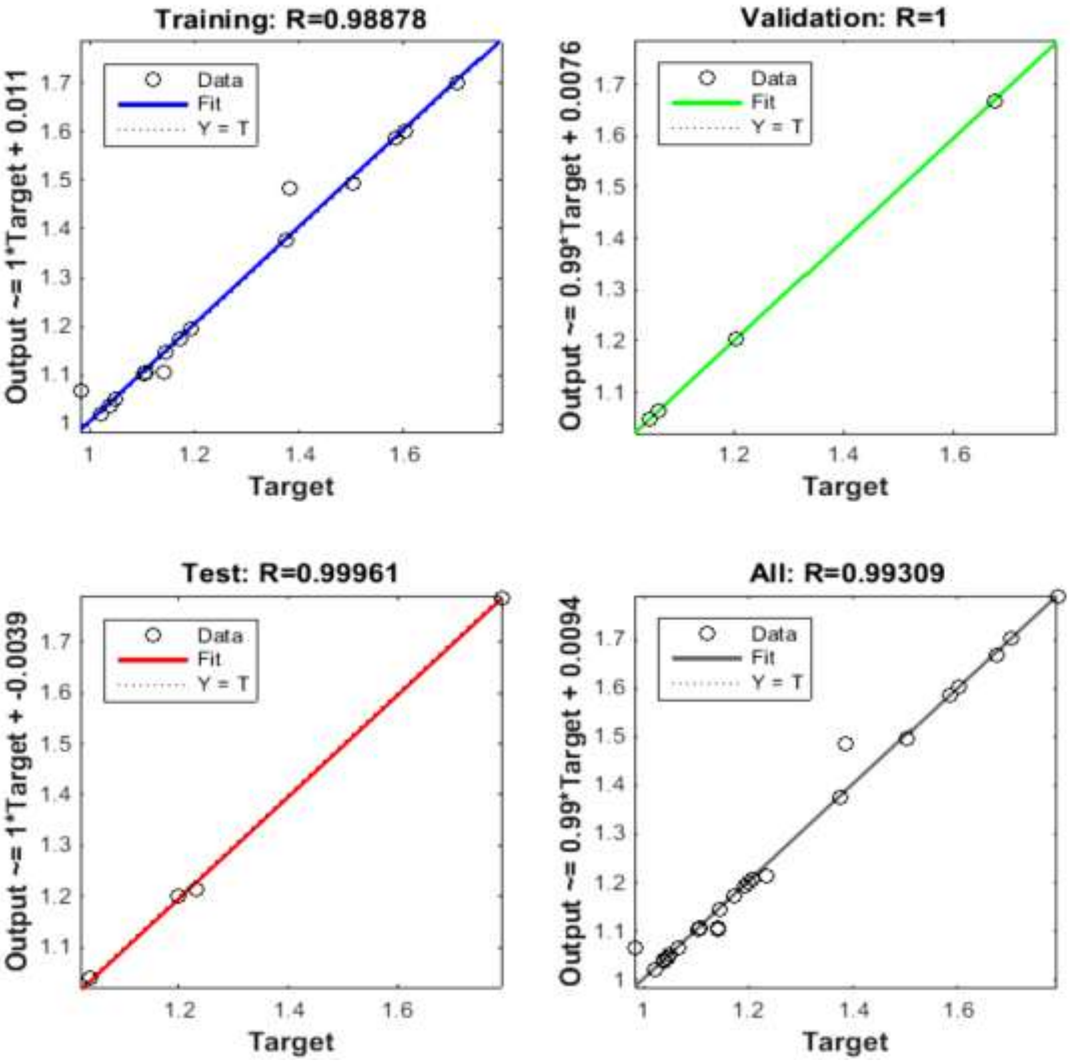

Figure 3 Training, validation and test data vs target values

The predicted and measured values of Mod Diameter have been shown in Table 2 along with error values which are negligible as compared to original values.

Table 2 Predicted and Measured values of dimensional accuracy

S.No.	Measured Value Modified D= 0.7ΔD + 0.1ΔL + 0.1ΔW + 0.1ΔT	Predicted Value Modified D = 0.7ΔD + 0.1ΔL + 0.1ΔW + 0.1ΔT	Error
1.	1.050679	1.0507	-2.14E-05
2.	1.142726	1.106069	0.036657
3.	1.046626	1.046659	-3.27E-05
4.	1.037772	1.037846	-7.38E-05
5.	1.146191	1.146132	5.90E-05
6.	1.020151	1.020218	-6.71E-05
7.	1.065772	1.065717	5.53E-05
8.	1.173222	1.173303	-8.08E-05
9.	1.142047	1.104994	0.037053
10.	0.981957	1.066525	-0.08457
11.	1.206135	1.206125	1.03E-05

12.	1.200713	1.200755	-4.20E-05
13.	1.105809	1.10584	-3.13E-05
14.	1.233357	1.215097	0.01826
15.	1.193824	1.193845	-2.09E-05
16.	1.039065	1.040606	-0.00154
17.	1.194611	1.194554	5.67E-05
18.	1.102642	1.102704	-6.18E-05
19.	1.376071	1.376114	-4.28E-05
20.	1.701737	1.701708	2.85E-05
21.	1.672809	1.668604	0.004205
22.	1.586633	1.586371	0.000262
23.	1.78963	1.786853	0.002777
24.	1.376966	1.376977	-1.06E-05
25.	1.384358	1.484185	-0.09983
26.	1.602274	1.602259	1.52E-05
27.	1.50154	1.494949	0.006591

The graphs are also plotted for gradient and validation conformation at different values of epochs as shown in Figure 4.

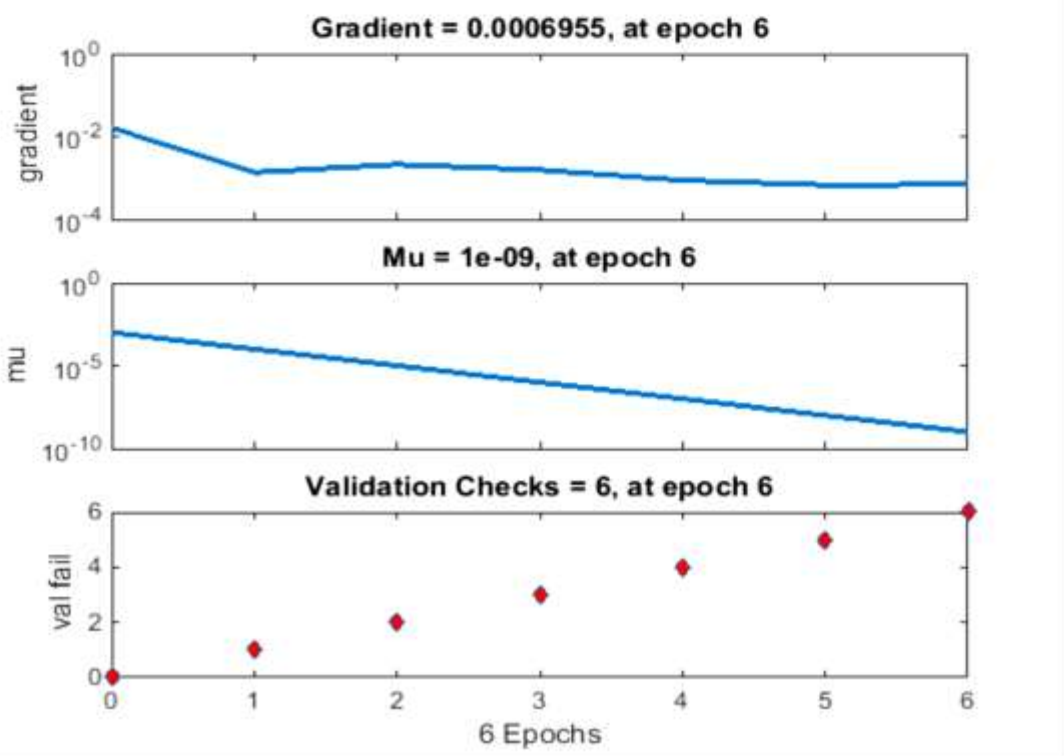

Figure 4 Gradient and validation results

Also, the mean squared error has been plotted at different epochs which indicated the higher prediction efficiency and validity of Genetic Algorithm as shown in Figure 5.

The recommended parametric settings were 0.140184, 0, 0, 0.5064, 0.008 for layer thickness, orientation angle, raster angle, raster width and air gap respectively with objective function value of 0.8048.

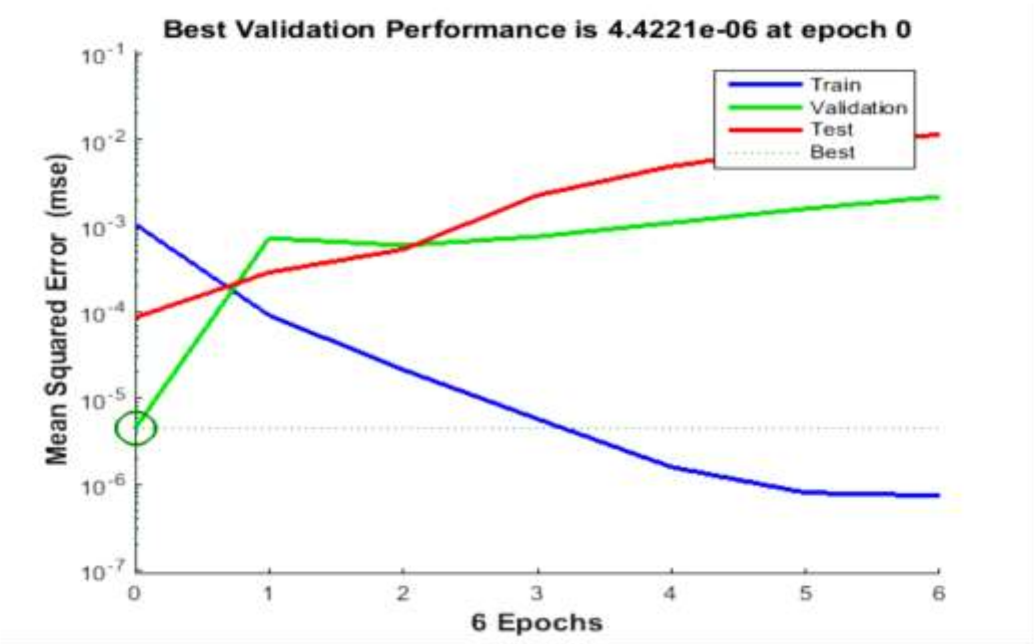

Figure 5 Mean squared error at different epochs

4. Conclusions

The study has been conducted to optimize the process parameters of Plastic Jet Printing (PJP) process of polymeric biocomposites along with prediction and validation of results. The analysis was performed to reduce the dimensional variability of PJP-derived polymeric biocomposite parts which is major hindrance against specific applications of this disruptive technology. The individual weightage was given to each output i.e., length, width, thickness and diameter. Thus, modified equation was created to analyse the impact of process parameters on dimensional accuracy of polymeric biocomposite test specimens. Genetic Algorithm was implemented on complex situation of PJP process which indicated comparatively greater prediction efficiency. Moreover, the validation study supported the prediction results which suggested the further implementation of Genetic Algorithm for solving surface roughness issues at different faces of polymeric biocomposite test specimens. Also, the tensile strength, compressive strength, hardness and wear resistance of test specimen can be improved by implementing this advanced optimization technique.

Conflicts of Interest:

The authors declare no conflict of interest.

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