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# Dimensional accuracy analysis of Material extrusion Additive manufacturing process for polymeric biocomposites using Genetic Algorithm: A computational optimization approach

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**Abstract:** Material extrusion Additive Manufacturing (MEAM) has been widely accepted technology for development of medical implants, automobile and aerospace parts, prototypes, jewellery and other end use components. The technique facilitates desktop printing with cleaner environment and lesser pollution as compared to traditional manufacturing techniques. Moreover, the time and cost required for fabrication of polymeric biocomposites are comparatively lesser as compared to rival additive manufacturing techniques. The dimensional accuracy of MEAM derived polymeric biocomposite parts has been a matter of interest for researchers due to inherent defect of layer by layer manufacturing which induces considerable stair stepping and dimensional variability in addition to surface finish. The present study aims to optimize the process parameters of MEAM predicated polymeric biocomposites using genetic algorithm technique which would yield minimum dimensional variability. The width, length, thickness and diameter of test polymeric composite parts was measured before and after fabrication which led to development of single equation with different weightage to each dimension. The genetic algorithm predicted optimal parametric settings and 99.99% of validation was achieved for objective function.

**Keywords:** Material extrusion Additive Manufacturing, Genetic Algorithm, Dimensional Accuracy, prediction, Optimization

## 1. Introduction

Additive Manufacturing (AM) technology is actually a set of varied Rapid Tooling methods which emphasized on creation of complicated geometries precisely simultaneously reducing the manufacturing time and cost [1, 2]. Alternately called as Freeform fabrication or maybe layer Manufacturing, this brand new race of production methods gets rid of the usage of standard tools, fixtures, jigs, dies with minimum human intervention [3-5]. Fused Deposition Modeling (FDM) is actually getting extensive use as it integrates Rapid Computer and Prototyping Aided Design technology while offering flexibility of utilizing various materials, shapes to attain desired properties [6, 7]. Material Extrusion Additive Manufacturing (MEAM) is a subset of Additive Manufacturing processes which provide easy, low cost and faster fabrication of parts as compared to subtractive manufacturing techniques [8-10].

Figure 1 depicts the working principle and basic components of MEAM process. In MEAM, at first, the part was created in robust designing software and transformed to STL format for more processing [11, 12]. Afterwards, toolpaths are actually produced by slicing software which tessellated he part into small slices rather than complicated structure [13-15]. These toolpaths drive stepper motors in pre-defined path that are more connected to extruder head. The extruder head comprises of rollers and heated nozzle where plastic filament of build is actually furnished as well as deposited on build platform [16, 17]. The build material in form of small wire is actually heated to a temperature somewhat under the melting point to ensure that semi molten bead is exactly layered on platform [18-20]. The extruder head moves in Y and X direction while table moves in Z direction which results to 3 dimensional deposition of semi molten plastic material filament [21, 22]. In addition of part material, support material is extruded by another nozzle to offer strength to overhanging parts. The support material is actually water soluble. The portion is actually prepared within few hours and ready to use after removal of support structures [23-29]. Now-a-days, commercial FDM machines have provision to alter various process parameters to attain desired characteristics in final parts [24, 30-57].

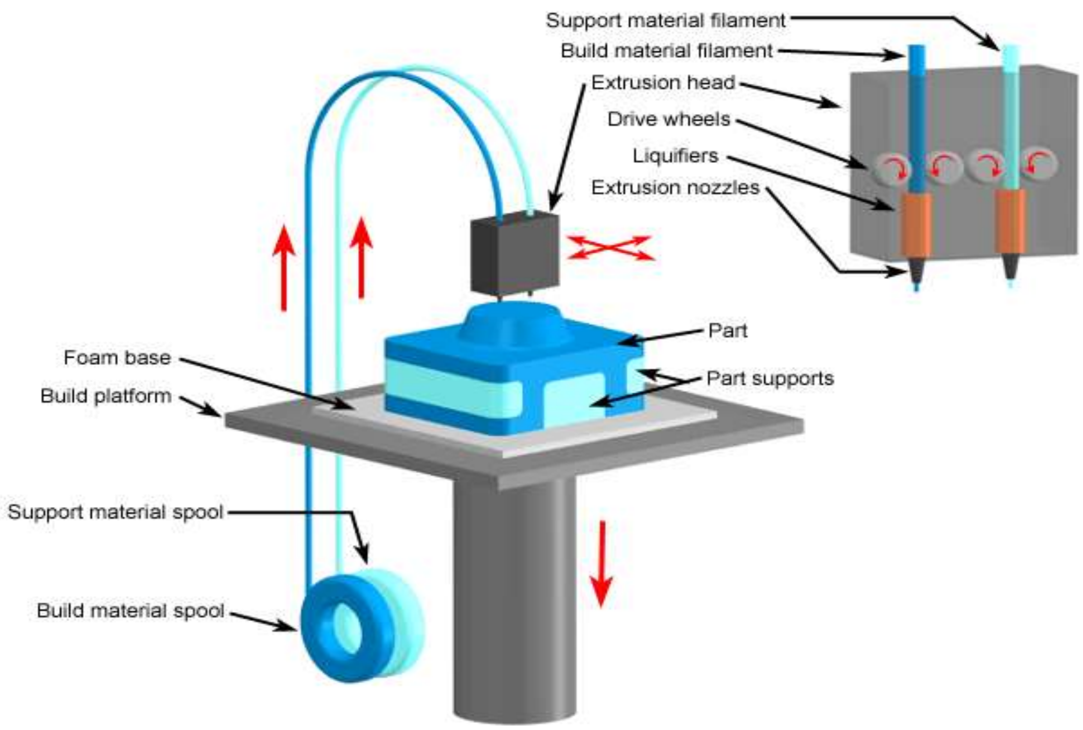



Figure 1 Basic components and working of MEAM based polymeric composites process

## 2. Methodology

The dimensional accuracy of polymeric biocomposites-based test parts has been measured using Coordinate Measuring Machine and measured dimensions were compared with CAD data. The variation in thickness, length, width and diameter was measured as difference between original and measured dimensions. The experiments were conducted at five different input factors of MEAM i.e., layer thickness, orientation angle, raster angle, raster width and air gap with three levels of each output. Table 1 describes the experimental plan along with response parameters for each experiment.

Table 1 Experimental plan and dimensions

| | **Factors** | | | | | **Response** |
|---|---|---|---|---|---|---|
| **Exp. No** | **Layer Thickness (mm) A** | **Orientation Angle (°) B** | **Raster Angle (°) C** | **Raster width (mm) D** | **Air Gap (mm) E** | **Mod T=0.7ΔT + 0.1ΔL + 0.1ΔW + 0.1ΔD** |
| 1 | 0.127 | 0 | 0 | 0.4064 | 0 | 2.206477 |
| 2 | 0.127 | 15 | 0 | 0.4564 | 0.004 | 2.896412 |
| 3 | 0.127 | 30 | 0 | 0.5064 | 0.008 | 2.001495 |
| 4 | 0.127 | 0 | 30 | 0.4564 | 0.004 | 2.043847 |
| 5 | 0.127 | 15 | 30 | 0.5064 | 0.008 | 2.851504 |
| 6 | 0.127 | 30 | 30 | 0.4064 | 0 | 2.026616 |
| 7 | 0.127 | 0 | 60 | 0.5064 | 0.008 | 2.371847 |
| 8 | 0.127 | 15 | 60 | 0.4064 | 0 | 2.979389 |
| 9 | 0.127 | 30 | 60 | 0.4564 | 0.004 | 2.798935 |
| 10 | 0.178 | 0 | 0 | 0.4564 | 0.008 | 1.987088 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | 0.178 | 15 | 0 | 0.5064 | 0 | 3.212282 |
| 12 | 0.178 | 30 | 0 | 0.4064 | 0.004 | 3.306102 |
| 13 | 0.178 | 0 | 30 | 0.5064 | 0 | 2.711996 |
| 14 | 0.178 | 15 | 30 | 0.4064 | 0.004 | 3.539671 |
| 15 | 0.178 | 30 | 30 | 0.4564 | 0.008 | 3.299046 |
| 16 | 0.178 | 0 | 60 | 0.4064 | 0.004 | 2.243509 |
| 17 | 0.178 | 15 | 60 | 0.4564 | 0.008 | 3.149945 |
| 18 | 0.178 | 30 | 60 | 0.5064 | 0 | 2.707329 |
| 19 | 0.254 | 0 | 0 | 0.5064 | 0.004 | 4.727273 |
| 20 | 0.254 | 15 | 0 | 0.4064 | 0.008 | 6.85594 |
| 21 | 0.254 | 30 | 0 | 0.4564 | 0 | 6.729496 |
| 22 | 0.254 | 0 | 30 | 0.4064 | 0.008 | 6.188542 |
| 23 | 0.254 | 15 | 30 | 0.4564 | 0 | 7.493019 |
| 24 | 0.254 | 30 | 30 | 0.5064 | 0.004 | 4.632875 |
| 25 | 0.254 | 0 | 60 | 0.4564 | 0 | 4.738171 |
| 26 | 0.254 | 15 | 60 | 0.5064 | 0.004 | 6.154088 |
| 27 | 0.254 | 30 | 60 | 0.4064 | 0.008 | 5.508171 |

Afterwards, the data of four response variables was combined to form single equation with different weightages to each response. The 70% weightage was given to thickness while equal weightage of 10% was given to other dimensions.

Mod T=0.7ΔT + 0.1ΔL + 0.1ΔW + 0.1ΔD

The equation derived using regression analysis is given as:

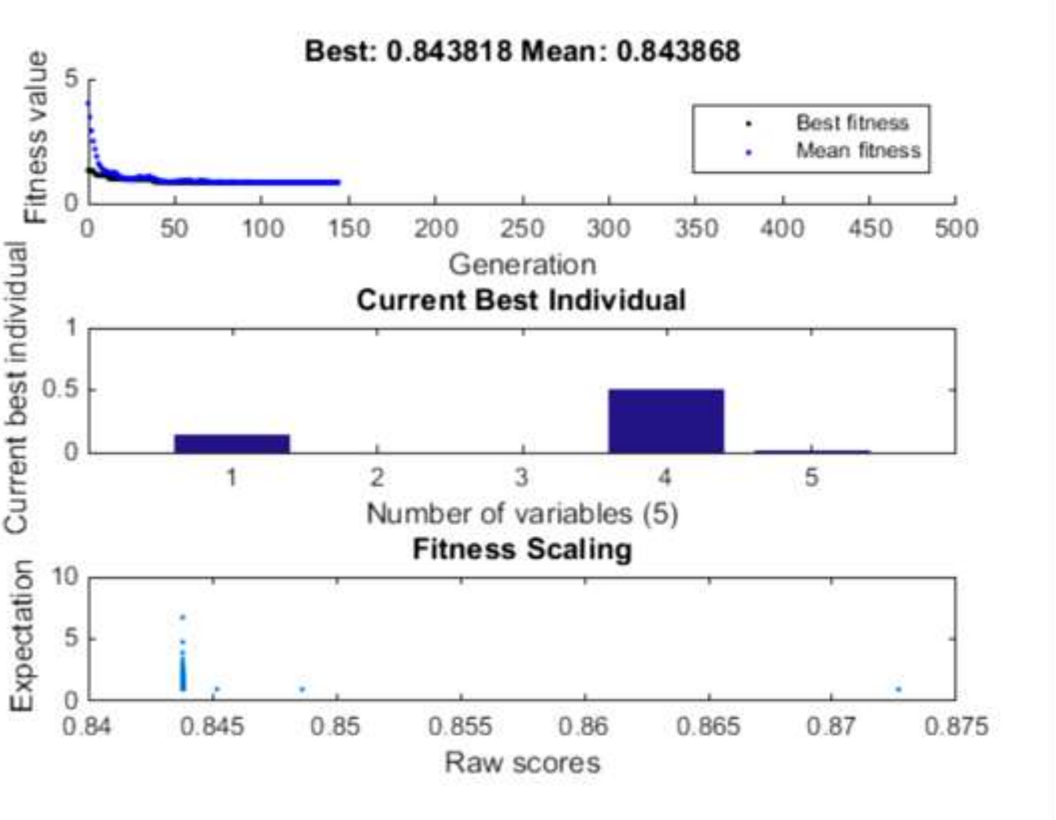
Mod T = -14.1 + 1.0 A + 0.109 B - 0.0572 C + 74 D - 68 E + 241.0 A*A - 0.00396 B*B - 0.000185 C*C- 68 D*D - 42 E*E - 0.109 A*B - 0.159 A*C - 127.0 A*D - 360 A*E + 0.000012 B*C+ 0.082 B*D + 1.58 B*E + 0.192 C*D + 1.88 C*E

## 3. Results and Discussions

The analysis using genetic Algorithm has been performed and charts are derived which show the fitness scaling, current best value and overall best values and means as shown in Figure 2. The charts are plotted between fitness value vs generation, current best value vs variable and expectations vs raw sores.

Figure 2 Fitness scaling and best values predicted by Genetic algorithm

The results yielded by genetic algorithm optimized and predicted the results with higher accuracy as compared to conventional




optimization techniques. It was predicted that optimum parameter settings would be 0.137325, 0, 6.80x$10^{-5}$, 0.5064, 0.008for layer thickness, orientation angle, raster angle, raster width and air gap respectively with objective function value of 0.843.

The predicted and measured values of Mod Thickness 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 Dimension<br>Mod T=0.7ΔT + 0.1ΔL + 0.1ΔW + 0.1ΔD | Predicted Dimension<br>Mod T=0.7ΔT + 0.1ΔL + 0.1ΔW + 0.1ΔD | Error |
|---|---|---|---|
| 1. | 2.206477 | 2.20473 | 0.001747 |
| 2. | 2.896412 | 2.899016 | -0.0026 |
| 3. | 2.001495 | 2.004994 | -0.0035 |
| 4. | 2.043847 | 2.004025 | 0.039822 |
| 5. | 2.851504 | 2.422507 | 0.428997 |
| 6. | 2.026616 | 2.027949 | -0.00133 |
| 7. | 2.371847 | 2.373779 | -0.00193 |
| 8. | 2.979389 | 2.975053 | 0.004336 |
| 9. | 2.798935 | 2.796963 | 0.001972 |
| 10. | 1.987088 | 2.010358 | -0.02327 |
| 11. | 3.212282 | 3.208274 | 0.004008 |
| 12. | 3.306102 | 3.31118 | -0.00508 |
| 13. | 2.711996 | 2.036712 | 0.675284 |
| 14. | 3.539671 | 3.5205 | 0.019171 |

| | | | |
|---|---|---|---|
| 15. | 3.299046 | 3.304609 | -0.00556 |
| 16. | 2.243509 | 2.245117 | -0.00161 |
| 17. | 3.149945 | 3.172134 | -0.02219 |
| 18. | 2.707329 | 2.489238 | 0.218091 |
| 19. | 4.727273 | 4.73351 | -0.00624 |
| 20. | 6.85594 | 6.845268 | 0.010672 |
| 21. | 6.729496 | 6.725871 | 0.003625 |
| 22. | 6.188542 | 6.12604 | 0.062502 |
| 23. | 7.493019 | 7.479497 | 0.013522 |
| 24. | 4.632875 | 4.269575 | 0.3633 |
| 25. | 4.738171 | 4.74279 | -0.00462 |
| 26. | 6.154088 | 6.147507 | 0.006581 |
| 27. | 5.508171 | 5.497527 | 0.010644 |

The results were successfully validated by Genetic Algorithm which shows higher accuracy of dimensional values. Figure 3 shows the performance of best validation results.

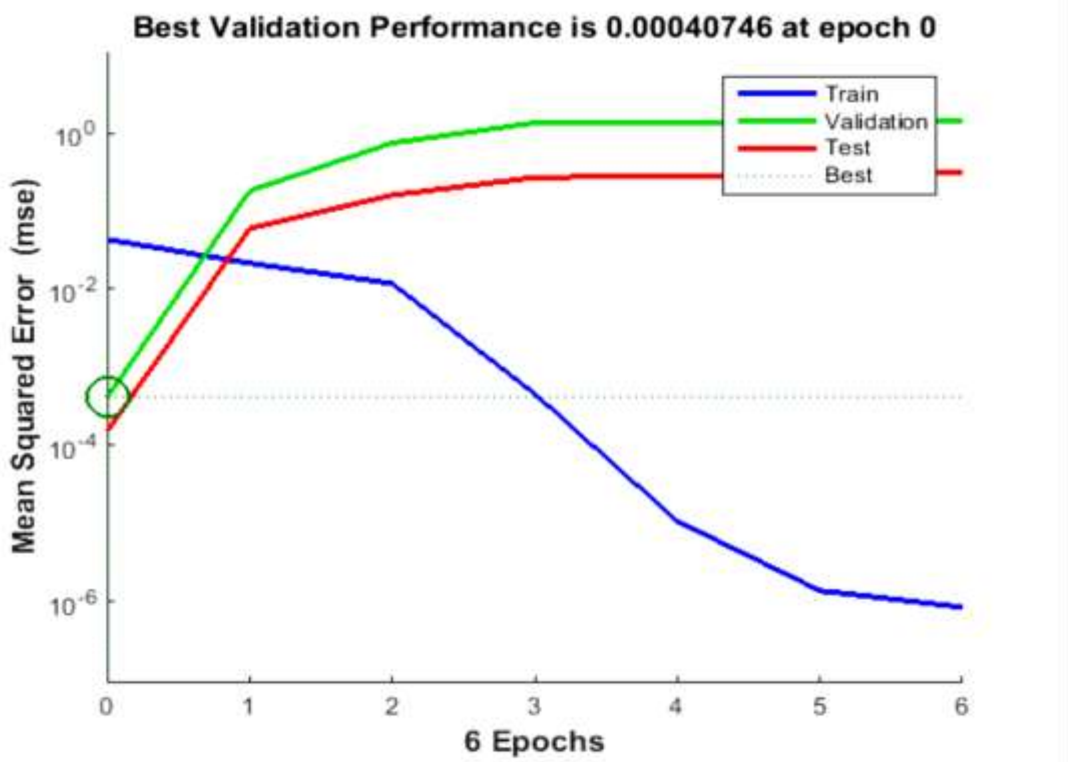



Figure 3 Performance of best validation at different epochs

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.

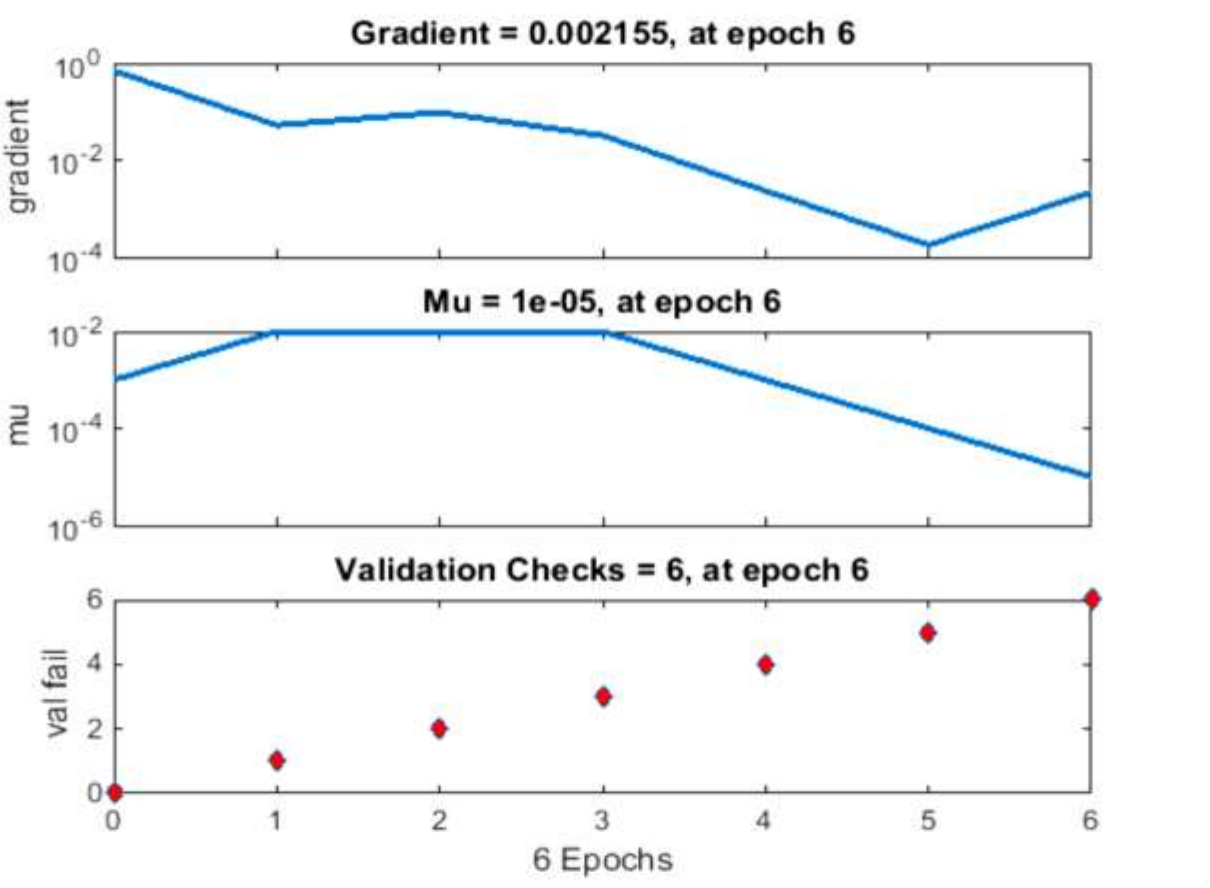



Figure 4 Gradient and validation results

The results depicted in figure 4 are derived from Genetic Algorithm interface during prediction and analysis at different values of epochs.

## 4. Conclusions

Material extrusion Additive Manufacturing (MEAM) utilizes uses the deposition of semi molten thermoplastic polymeric composite beads by robotic nozzle on numeric controlled platform. The layer by layer phenomenon of deposition of facilitates rapid fabrication but adversely affects the surface quality and dimensional accuracy. Although number of optimization and prediction techniques have been implemented but dimensions with different weightages have never been studied. The efficacy of Genetic Algorithm has been investigated using dimensional accuracy of MEAM-based polymeric biocomposites parts as response variables. The results showed that 0.137325, 0, 6.80x10-5, 0.5064, 0.008 were optimum values of layer thickness, orientation angle, raster angle, raster width and air gap respectively for achieving minimum dimensional variability. The study can be further extended to evaluate the surface roughness at different faces of polymeric biocomposites derived test part. Also, the different aspects of mechanical strength such as tensile strength, compressive strength, impact and flexural strength must be evaluated.

**Conflicts of Interest:**

The authors declare no conflict of interest.

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