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Dimensional Investigation of Material Extrusion Based AM Part

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Abstract

Now a day's additive manufacturing plays a vital role in industrial application. Material Extrusion based 3D printed parts often face inherent limitations in quality, such as geometric inaccuracies, surface roughness, and reduced strength, especially when compared to those made through traditional or more refined manufacturing methods. However, this system provides notable advantages for producing parts from materials like ABS by optimizing critical material extrusion based AM machine process parameters, such as layer thickness, infill percentage, and infill pattern design. The aim of this study is to develop an optimized set of machining parameters that can help produce parts with improved geometric accuracy. Factorial analysis based design of experiment (DOE) method is a flexible approach that is used to understand the impact of multiple variables and their interactions to find out the best combination of factor levels setting for improving the dimensional accuracy of test specimens. From result it is concluded that, interaction between layer thickness and infill percentage, layer thickness, interaction between infill percentage and infill pattern design, & interaction between layer thickness and infill percentage have the greatest impact on the accuracy of the part in terms of length (X1), length (Y1), length (Z1), & diametrical length (D1) respectively.

Keywords: Additive manufacturing, ABS, infill percentage, infill design, layer height.

INTRODUCTION

Additive manufacturing (AM), commonly referred to by names like 3D printing, rapid prototyping, layered manufacturing, solid free form fabrication technique, and digital fabrication, has indeed undergone significant evolution since its commercialization in the 1980s. Initially, AM technologies were primarily used for rapid prototyping, allowing designers and engineers to create physical models from digital files quickly for visualizing the product. Over the years, advancements in materials, processes, and applications have broadened the scope of AM. Today, it's employed in diverse fields such as aerospace, automotive, healthcare, and consumer products. Techniques like selective laser sintering (SLS), fused deposition modeling (FDM), and stereolithography (SLA) have become prevalent, each offering unique advantages depending on the application. The ongoing research and development in AM are paving the way for innovations such as multi-material printing, bioprinting, and on-demand manufacturing, which could revolutionize supply chains and reduce waste. As the technology continues to evolve, it holds the potential to transform how products are designed, manufactured, and delivered [1-4]. Additive manufacturing allows for the customized fabrication of parts in layers, enabling intricate designs that are often difficult or impossible to achieve with traditional manufacturing methods. This layer-by-layer approach not only facilitates complex geometries but also streamlines the overall production process. Additive manufacturing and iterative design allow for faster adjustments and improvements, significantly shortening the time from concept to final product. It enables on-demand

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production, reducing the need for extensive inventories and complex supply chains. Parts can be printed as needed, minimizing delays. Traditional manufacturing methods often result in significant material waste. In contrast, AM uses only the material necessary for the part, resulting in minimal scrap. AM typically requires less tooling than traditional methods, which can involve costly molds and fixtures. This lowers initial costs and speeds up setup times. The ability to print multiple parts simultaneously and the absence of complex assembly processes lead to shorter lead times for production. Overall, these advantages make additive manufacturing a compelling choice for industries seeking efficiency, flexibility, and innovation in their production processes [5-11]. AM minimizes the energy consumed during production, which contributes to lower carbon production and reduced greenhouse gases emissions, as we know that this technique is a direct final part production oriented nature that significantly reduces energy and fuel requirements compared to traditional manufacturing methods. This environmental advantage positions AM as a promising green technology, aligning with the global push toward sustainable practices. AM has evolved to play a more central role in various industries. Its applications now extend beyond prototyping to include end-use parts, customized products, and complex assemblies across sectors such as aerospace, automotive, healthcare, and construction. As AM technology continues to advance, its potential to innovate and streamline manufacturing processes further enhances its appeal. The ability to produce lightweight, high-strength components, optimize material usage, and shorten supply chains makes AM a powerful solution for achieving sustainability goals while meeting the demands of modern production. This shift in perception underscores AM's growing importance in the future of manufacturing [12-17]. Additive manufacturing is a group of modern manufacturing technology that encompasses a range of techniques that enable the direct fabrication of objects from directly CAD representation without the need of any part specific tooling requirement such as tools, jigs, and fixtures, etc. AM techniques enable complex geometries, customization, and rapid prototyping, making them invaluable in industries ranging from aerospace to healthcare. As the technology continues to develop, its applications and relevance in the manufacturing landscape only grow, reinforcing its integral role in shaping the future of production [18-20]. The evolution of additive manufacturing techniques over the past few decades has been remarkable, marked by significant advancements in technology, materials, and applications. This journey reflects a continuous push toward improving efficiency, versatility, and performance. Early Developments (1980s-1990s): The origins of AM can be traced back to the 1980s with the advent of technologies like stereolithography (SLA) developed by Chuck Hull. During this period, 3D printing began primarily as a tool for rapid prototyping. Expansion of Techniques (1990s-2000s): The 1990s saw the emergence of various AM techniques such as selective laser sintering (SLS), fused deposition modeling (FDM), and laminated object manufacturing (LOM). These methods expanded the range of materials and applications, paving the way for greater customization and complexity in designs. Rise of 3D Printing (2000s-2010s): The early 2000s popularized the term "3D printing," further integrating AM into various industries. Desktop 3D printers became available, making the technology accessible to hobbyists and small businesses. This democratization spurred innovation and experimentation. Advancements in Materials (2010s-present): The last decade has seen significant advancements in materials for AM, including metals, ceramics, and bio-materials. The development of multi-material printing and new composite materials has expanded the scope of applications, especially in fields like aerospace and healthcare. Industry Integration (2010s-present): AM is increasingly recognized for its potential in producing end-use parts rather than just prototypes. Industries are adopting AM for supply chain optimization, customization, and sustainability. This comprehensive timeline reflects not only the technological advancements but also the shifting perceptions of AM's role in modern manufacturing. As AM techniques continue to evolve, they hold great promise for further innovation across various sectors [21-26]. Regular reports from researchers and industry leaders highlighted the advancements in additive manufacturing technologies and their corresponding applications that extensively enhanced the market variety and technological compatibility and above developments, showcasing the remarkable flexibility and variability in the attributes of AM-produced parts. One of the standout features of AM is its ability to create unique geometries that are challenging or impossible to achieve with traditional manufacturing methods. For instance, AM techniques can fabricate lightweight hollow structures, proof of concept models, form and fit models, flow analysis models, surgery rehearsal models, and complex mold cavities type of product. These innovations not only optimize performance but also lead to more efficient designs, particularly in high-performance applications like aerospace and automotive engineering. Economically, transitioning from conventional manufacturing to AM can yield significant cost savings—often exceeding 50% in sectors like aerospace and automotive [2]. Additive manufacturing significantly shortens the product design development cycle, which enable rapid product growth and quicker time-to-market for commence. This agility is particularly beneficial in competitive industries where speed is essential. The technology allows for the creation of metal parts with exceptional strength-to-weight ratios, unrestricted by conventional design limitations. The intricate geometries and high-quality features achievable through AM contribute to enhanced performance and functionality in various applications. In addition to these advantages, AM is recognized as a green manufacturing method. The reduction of material waste and scrap, along with decreased noise pollution during the manufacturing process, aligns with sustainable practices. This environmental benefit further enhances AM's appeal in today’s market, where companies are increasingly focused on sustainability. Another key advantage of AM is its compatibility with office environments. Unlike traditional manufacturing processes that often require specialized workshops, AM machines can be integrated into standard office spaces, making them more accessible and worker-friendly. This shift minimizes the need for extensive manufacturing infrastructure. Moreover, the elimination of jigs and fixtures due to elimination of part specific tooling nature of AM leads to significant cost savings. This feature not only reduces initial investment but also allows for greater flexibility in production, as parts can be designed and printed without the constraints of traditional tooling. Overall, these strengths position additive manufacturing as a transformative technology in modern manufacturing [27]. Strategically arranging multiple components within a single build, manufacturers can maximize the use of available space, reduce print times, and improve material efficiency. This optimization not only increases production efficiency but also lowers energy consumption, as multiple parts can be fabricated in one cycle rather than sequentially. Additionally, it minimizes material waste, as the layout can be designed to utilize leftover spaces effectively. Incorporating layout optimization into the AM process not only enhances productivity but also contributes to more sustainable manufacturing practices, making it an essential aspect of modern AM strategies [3]. By streamlining the design and production processes, AM allows companies to bring products to market faster while reducing overall manufacturing expenses. Time, cost, flexibility, quality and variability gives AM not only as a cost-effective solution but also as a transformative technology that enhances manufacturing capabilities in various industries [28]. Design and fabrication of product with different properties is achieved using additive manufacturing technology and it is a significant advantage of the technology. This capability allows for the customization of material characteristics such as strength, weight, and thermal conductivity according to specific application requirements [12, 25]. Although extensive literature review work has been done on additive manufacturing, and it is found that a small research work has been done to investigate effect of various key factors such as material selection, printer setting, and processing parameters, for the improvement of 3D Printed parts in term of mechanical, surface, dimensional and overall quality of the fabricated product. Extrusion based additive manufacturing system offer an ideal conceptual and functional modeling with immense flexibility, lead time, reliability, cost, and reasonable accuracy over other the AM technique. Literature reveals that numerous processing parameters are critically associated with extrusion-based additive manufacturing system, that significantly affecting the quality and functionality of the manufactured product. Therefore, the careful selection and optimization of these processing parameters are essential for enhancing the strength, stability, and overall quality of the fabricated object. By fine-tuning of variables on the machine during fabrication of product, manufacturers can get more reliable and functional 3D printed parts, thus improving the performance of 3D Printer.

MATERIALS AND EXPERIMENTAL

The Taguchi design of experiment constitutes a preeminent analytical framework for elucidating the influence of 3D printing process parameters on the output characteristics of the objective function. A large number of machine process parameters are involved with the manufacturing system during fabrication of the product, thus in Taguchi design of experiment the selection and identification of significant and insignificant machine process parameter is required in the early stage of experimentation. 3D printing (3D-OSP) represents a recently developed rapid prototyping (RP) process facilitating the fabrication of parts. Previous research has identified parameters such as print speed, slice height, orientation, infill angle, and shell thickness as contributing significantly to the 3D open-source printer's performance. In the present investigation, three process parameters, each examined at two levels, are considered. Parameters such as layer height, infill percentage and infill pattern design at two levels are considered as shown in Table 1. In this study Carbon chain copolymer based Acrylonitrile Butadiene Styrene (ABS) is used for the fabrication of test specimens using 3D open source printer. Acrylonitrile Butadiene Styrene is a two stage polymer structure, comprising a glassy phase consisting of styrene-acrylonitrile copolymer and a rubbery phase comprised of styrene-butadiene copolymer. Synthetic monomer based Acrylonitrile obtained from ammonia and propylene, petroleum hydrocarbon based butadiene produced by the C4 fraction of staem cracking, dehydrogenation of ethyl benzene gives styrene based monomer, and reaction of ethylene and benzene produces hydrocarbon. The ABS terpolymer, denooed by a molecular formula of $((C_8H_8)_x(C_4H_6)_y(C_3H_3N)_z)$, derives its name from the acronyms of its composing monomers: acrylonitrile, butadiene, and styrene. These three monomers are usually added together in definite proportions such as 15-40% acrylonitrile, 5-35% butadiene and 40-65% styrene. A three-dimensional CAD model of a conceptual design is created utilizing a software tool, such as SolidWorks, capable of generating STL-formatted files, which are subsequently imported into machine-specific software and above software executes necessary operations, including tessellation of the 3D CAD geometry of product and the generation of 3D printing path head movement, as well as 3D printing machine parameter optimization. Following these processes, final print instructions are transmitted to the 3D printing fabrication system as shown in Figure 1 to facilitate the creation of three-dimensional test parts.

Table 1. Different factors and their level for part fabrication using 3D Printer.

Factors and their level				
Factors for 3D Printer	***Symbol***	***Level***		***Unit***
		1	2	
Layer Height	LH	0.1	0.2	mm
Infill Percentage	IP	15	25	%
Infill Pattern Design	IPD	Triangular	Honeycomb	-

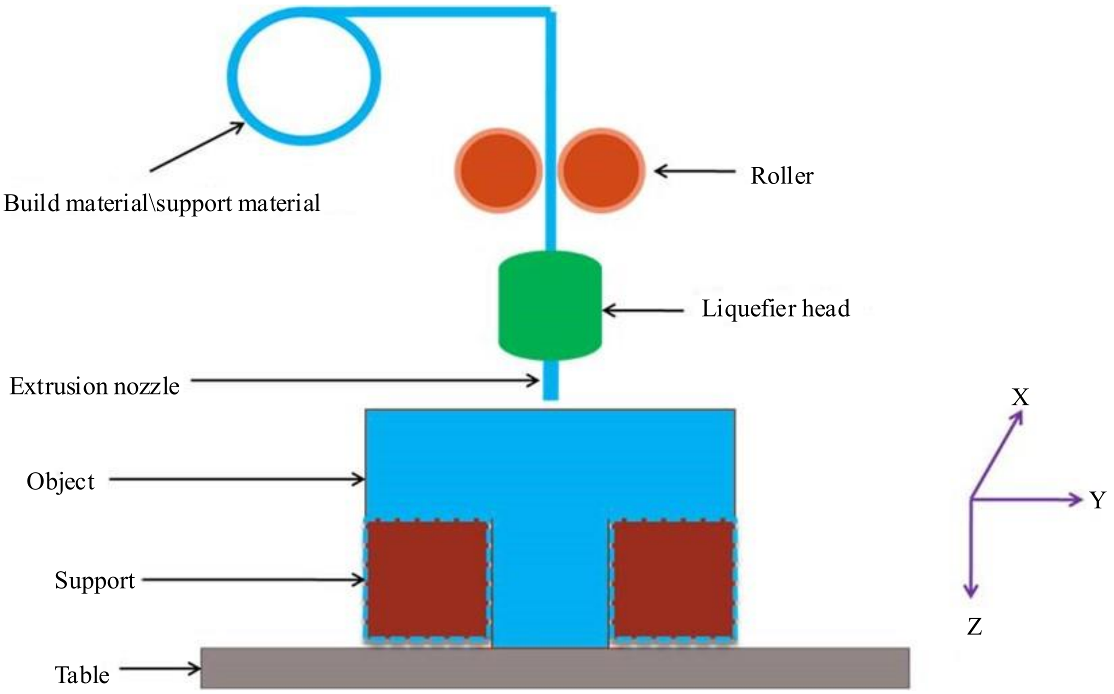

Figure 1. Schematic diagram of 3D open source printer [29].

The extrusion head features a singular nozzle, positioned in direct opposition to the fabrication direction of the specimen. Exhibiting mobility in the X-Y plane, while the platform oscillates within the Z plane, this configuration facilitates the precise deposition of model ABS material in accordance with pre-programmed part geometry generated using three dimensional software. The aforementioned ABS material, comprising in the form of filaments with a diameter of 1.75mm and specific gravity of 1.05g/cm³, is supplied to the extruder nozzle head via an automated feeding system. The thermal transformation occurs at a temperature of 245 °C upon entering the extrusion head; the ABS filaments undergo a reduction in diameter to 0.45mm in response to applied pressure by the feeding system. Ultimately, the transformed form of ABS filaments is discharged as semi-viscous material onto the machine build platform during the sequential deposition of each layer. All the test specimens are fabricated using a extrusion based 3D printed additive manufacturing system. In this 3D printer, a single nozzle based extrusion head have been used to extrude the semi-viscous form of ABS material in layered fashion onto the build platform to build the complete object according to the CAD model geometry. An experimental process was divided into two sequential stages. Initially, fabrication of test specimens was undertaken through modulation of process parameters. Subsequently, dimensional analyses were conducted, involving assessments of percentage length variation along the X, Y, and Z axes of the specimen build (denoted as X1, Y1, and Z1, respectively), as well as percentage changes in diametrical dimension (D1). These measurements were obtained by utilizing a vernier caliper and we also know that this instrument measure the interior and exterior dimension of the object very precisely. External jaws of vernier caliper are used to measure the dimension of the object. Taguchi method was implemented to find the impact of process variables on the part accuracy. In this research three process parameters each at two levels are considered. Parameters such layer height, infill percentage and infill pattern design at two levels are considered as shown in Table 1. According to the machine parameter and their level a Taguchi's orthogonal array was generated using Minitab 16 to conduct the experiments. Formula (Eq. 1) given below is used for the calculation of percentage change in geometrical dimensions [28]. Traditional experimental design methodologies are limited in their application due to their complexity and the requirement of conducting extensive experimentation to investigate numerous process parameters of extrusion based 3D printing system. To address this challenge, the Taguchi method leverages an orthogonal array design, enabling the exploration of comprehensive attribute space through a minimized number of experiments. Empirical findings are subsequently converted into a signal-to-noise (S/N) ratio, which quantifies the impact of each process parameter and its deviation from the desired value. This signal-to-noise ratio is calculated as the mean (signal) to standard deviation (noise) ratio. Eqs (2)-(4) are showing the various types of available signal-to-noise ratio. The aim of present experimental run is to trim down the geometrical changes in the dimension of the part build in different direction by varying the various fabricating process parameter. Here for the geometrical analysis the "smaller the better" quality characteristic is selected for the calculation of S/N ratio $\boldsymbol{\eta}$ [30].

$$Percentage\ Dimension\ Changes = \frac{|Measured\ value - Oroginal\ value|}{Oroginal\ value} \times 100 \tag{1}$$

$$Signal - to - noise\ \left(\frac{S}{N}\right) ratio\ for\ smaller\ is\ the\ better:\ \ \eta = -10\,log\frac{1}{n}\ \left(\sum x^2\right); \tag{2}$$

$$Signal - to - noise\ \left(\frac{S}{N}\right) ratio\ for\ larger\ is\ the\ better:\ \ \eta = -10\,log\frac{1}{n}\ \left(\sum \frac{1}{x^2}\right); \tag{3}$$

$$Signal - to - noise\ \left(\frac{S}{N}\right) ratio\ for\ nominal\ is\ the\ better:\ \ \eta = -10\,log\frac{1}{n}\ \left(\sum \frac{\bar{X}}{X_T^2}\right); \tag{4}$$

$$Calculation\ of\ Sum\ of\ Squares\ of\ the\ output\ variable:\ \ S_{OV} = \sum_{i=1}^{N} OV_i^2; \tag{5}$$

$$Calculation\ of\ Improvement\ Factor:\ \ IF = \frac{(\sum_{i=1}^{N} OV_i)^2}{N} \tag{6}$$

$$Total\ sum\ of\ squares\ T_{SS} = S_{OV} - IF \tag{7}$$

$$S_E = T_{SS} - S_{j;} \tag{8}$$

$$To\ find\ out\ mean\ sum\ of\ square\ error: \quad MSS_E = \frac{S_E}{DOF_E}; \tag{9}$$

$$Variance\ Ratio\ F_{VR} = \frac{MSS_j}{MSE_E}; \tag{10}$$

$$percentage\ contribution\ (\%PC) \quad = \frac{MSS_j}{\sum_{j=1}^{g} MSS_j}; \tag{11}$$

Analysis of Variance (ANOVA) is a statistically robust methodology employed to appraise experimental outcomes and calculation of ANOVA is facilitated through Equations (5)-(11). This ubiquitous technique serves the purpose of identifying inherent variances within groups of parameters being investigated. Aiming to isolate parameters whose collective contribution is significantly influential on total variation, ANOVA enables investigators to probe the variables at play. For experimentation, Minitab R16 software is strategically utilized, an analytical tool specifically designed for experimentation. ANOVA is utilized to elucidate the consequence of individual printing factors as well as their intricate interplay on part accuracy, via correlation with experimental results. Calibration of ANOVA involves adherence to a series of methodical steps, as detailed in prior research [28]. Subsequent to identifying the most significant parameter, the percentage contribution of each process parameter is computed through Equation (11), thereby providing an assessment of the relative contribution of each parameter to the overall error sum of squares.

RESULT & DISCUSSION

A quantitative experimental analysis was conducted to evaluate the dimensional variances in four distinct Cartesian axes: the X-direction (X1), the Y-direction (Y1), the Z-direction (Z1), and the diametrical dimension (D1), as shown in Table 2. In accordance with quality evaluation standards, the optimal approach was determined through a parametric design-based analysis of Eq. (2), employing the principle that smaller variance corresponds to superior quality. Analysis of variance (ANOVA) was employed to evaluate the dimensional variances in X1, Y1, Z1, and D1, with the results presented in Tables 3-6. Main effect graph of S/N ratio for three different geometrical characteristics is shown in Figure 2. Before any effort has been done, the use this statistical method as a forecaster for the measurement of quality characteristics, and feasible relations between the machine process parameter has to be deliberated. It is observe from Table 2 result that contraction is occur in the direction of dimension (X1) and dimension (Y1) but geometrical dimension rises in the direction of height (Z1). Contraction is take place due to presence of inner stress that causes shrinkage along the X-Y plane direction. The shrinkage is occurs due to decrease of ABS thermoplastic from melted temperature to the glass transition temperature of the above material. In present phase the inner stresses of the deposited material are not accumulated in spite of shrinkage, because at the above temperature state the produced material is able to attain a larger warp with a smaller amount force, and the ability to withstand from exterior force is near to the ground.

Table 2. Taguchi parameter design with change in geometrical dimension data.

S no.	Factors			Change in dimension			
	Layer height (LH)	*Infill percentage (IP)*	*Infill pattern design (IPD)*	*% change in dimension of part in X1 direction of build*	*% change in dimension of part in Y1 direction of build*	*% change in dimension of part in Z1 direction of build*	*% change in dimension of part in D1 direction of build*
1	1	1	1	0.341	2.744	4.444	1.852
2	1	1	2	0.387	1.357	2.857	2.130
3	2	2	1	0.310	0.913	3.809	1.185
4	2	2	2	0.248	0.337	1.904	0.649
5	1	2	1	0.449	4.357	4.761	0.630
6	1	2	2	0.480	0.959	1.587	0.796
7	2	1	1	0.558	0.580	3.492	0.241
8	2	1	2	0.604	0.302	5.079	0.963

Table 3. ANOVA table for X direction of build (X1).

Analysis of variance table for% change in dimension of part in X1 direction for ABS based 3D Printed Parts							
Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***	***% of Contributation***
LH	1	0.000481	0.000481	0.000481	0.44	0.626	0.451203
IP	1	0.020311	0.020311	0.020311	18.78	0.144	19.05276
IPD	1	0.000481	0.000481	0.000481	0.44	0.626	0.451203
LH*IP	1	0.081245	0.081245	0.081245	75.11	0.073	76.21196
LH*IPD	1	0.001082	0.001082	0.001082	1.00	0.500	1.014971
IP*IPD	1	0.001923	0.001923	0.001923	1.78	0.410	1.803872
Residual Error	1	0.001082	0.001082	0.001082			
Total	7	0.106604					

Table 4. ANOVA table for Y direction of build (Y1).

Analysis of variance table for% change in dimension of part in Y1 direction for ABS based 3D Printed Parts							
Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***	***% of Contributation***
LH	1	6.6348	6.6348	6.6348	18.09	0.147	47.47825
IP	1	0.3134	0.3134	0.3134	0.85	0.525	2.242672
IPD	1	3.9727	3.9727	3.9727	10.83	0.188	28.42841
LH*IP	1	0.0894	0.0894	0.0894	0.24	0.708	0.639741
LH*IPD	1	1.9313	1.9313	1.9313	5.27	0.262	13.82027
IP*IPD	1	0.6661	0.6661	0.6661	1.82	0.406	4.766573
Residual Error	1	0.3668	0.3668	0.3668			
Total	7	13.9744					

Table 5. ANOVA table for Z direction of build (Z1).

Analysis of variance table for% change in dimension of part in Z1 direction for ABS based 3D Printed Parts							
Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***	***% of Contributation***
LH	1	0.0504	0.0504	0.0504	0.11	0.795	0.431116
IP	1	1.8141	1.8141	1.8141	4.00	0.295	15.5176
IPD	1	3.2250	3.2250	3.2250	7.11	0.228	27.58627
LH*IP	1	0.4535	0.4535	0.4535	1.00	0.500	3.879185
LH*IPD	1	2.4691	2.4691	2.4691	5.44	0.258	21.12039
IP*IPD	1	3.2250	3.2250	3.2250	7.11	0.228	27.58627
Residual Error	1	0.4535	0.4535	0.4535			
Total	7	11.6906					

Table 6. ANOVA table for D Direction of build (D1).

Analysis of variance table for% change in dimension of part in D1 direction for ABS based 3D Printed Parts							
Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***	***% of Contributation***
LH	1	0.70188	0.70188	0.70188	4.27	0.287	24.27718
IP	1	0.46388	0.46388	0.46388	2.82	0.342	16.04505
IPD	1	0.04964	0.04964	0.04964	0.30	0.680	1.716988
LH*IP	1	1.26851	1.26851	1.26851	7.72	0.220	43.87623
LH*IPD	1	0.00831	0.00831	0.00831	0.05	0.859	0.287433
IP*IPD	1	0.23468	0.23468	0.23468	1.43	0.443	8.117298
Residual Error	1	0.16422	0.16422	0.16422			
Total	7	2.89111					

Table 7. Optimum level and significant parameter for four different geometrical characteristics.

Factors	Significant levels for different geometrical characteristic			
	% change in X1	*% change in Y1*	*% change in Z1*	*% change in D1*
Layer Height (LH)	0.2 mm	0.1 mm	0.2 mm	0.1 mm
Infill Percentage (IP)	15%	25%	15%	15%
Infill Pattern Design (IPD)	Honeycomb	Triangular	Triangular	Honeycomb
Significant	IP, LH*IP, IP*IPD	LH, IPD, LH*IPD	IPD, LH*IPD, IP*IPD	LH, IP, LH*IP

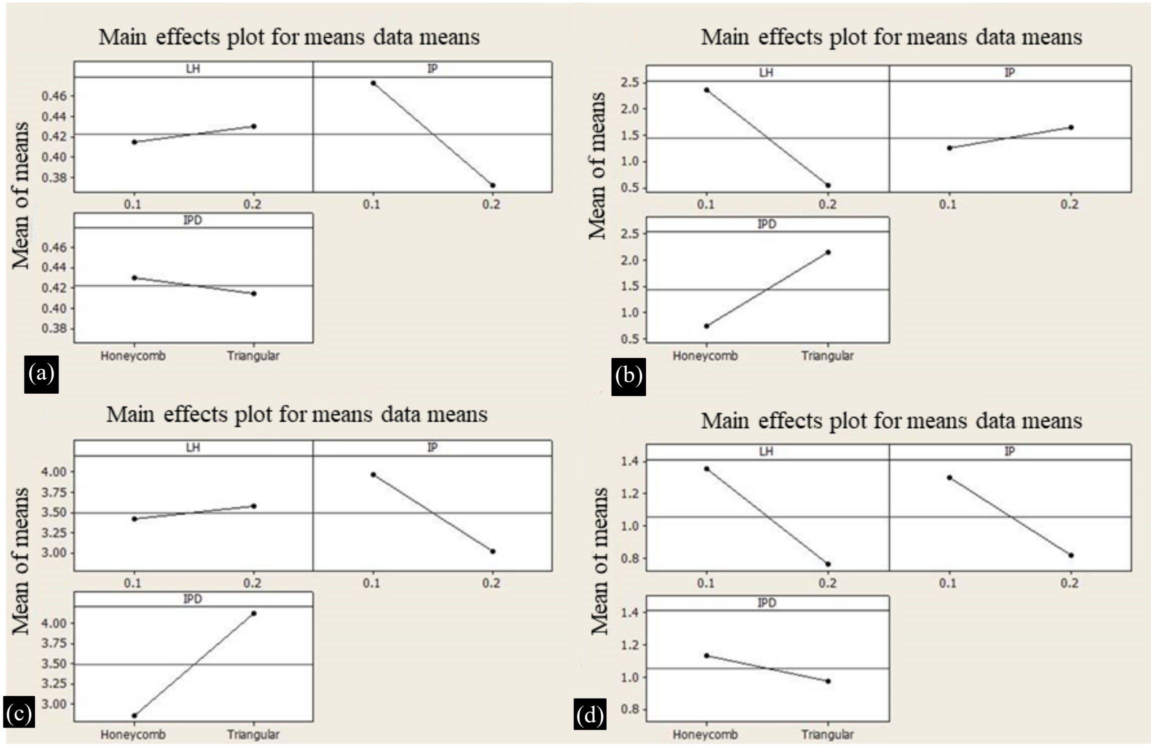

Figure 2. Main effect plot (a) X direction of build (X1) (b) Y direction of build (Y1) (c) Z direction of build (Z1), (d) D Diameter of build (D1).

The generation of inter-segmental stresses in ABS thermoplastic materials primarily occurs as a consequence of a temperature diminution from the glass transition temperature (Tg) to the chamber temperature (Te). This phenomenon gives rise to a non-uniform temperature gradient that can impact the object's morphology, induce deformation, and affect the integrity of the inner layers [29-30]. The specimen's dimensions undergo a reduction in the X1, Y1, and D1 directions, whereas the Z1 dimension experiences a corresponding increase. The emergence of inter-segmental stresses in thermoplastic ABS materials deposited onto a substrate is attributed to the contraction resulting from the cooling process, which encompasses the initial phase of transitioning from a molten state (Tm) to the glass transition temperature (Tg) and subsequent cooling to the chamber temperature (Te).

Variations in printing path speed during the layered deposition process can precipitate deviations in thermal gradient formation, thereby impacting part accuracy. Nozzle interruptions for tip cleaning purposes can cause arbitrary material deposition, requiring speed adjustments near part boundaries to maintain uniform deposition rates. Furthermore, the slicing rules employed by Extrusion based 3D Printing systems often fail to ensure unilateral tolerances throughout the prototype, often resulting in concomitant overcut and undercut issues. This oversight contributes to dimensional inaccuracies in post-processing due to inadequate tolerance management. Positive tolerance occurs when permissible deviations occur externally to the work-piece contour, whereas negative tolerance is characterized by internally sited tolerances. From (Table 7), it is observed that the infill percentage, interaction between layer thickness and infill percentage, interaction between infill percentage and infill pattern design affect the part accuracy most in length (X1). For the case of length (Y1) the layer thickness, infill pattern design, interaction between layer thickness and infill pattern design affect the part accuracy. Infill pattern design, interaction between layer thickness and infill pattern design, interaction between infill percentage and infill pattern design affect the part accuracy in part build direction height (H). For the case of length (D1) the layer thickness, infill pattern, interaction between layer thickness and infill percentage affect the part accuracy.

CONCLUSION

In current scenario additive Manufacturing plays a vital role in industrial application. In this paper three parameters taken as layer thickness, infill percentage and infill pattern design at level two are used to optimize ABS based 3D part, which is produced with the help of material extrusion based additive manufacturing technique. Shrinkage is occur in the direction of length (X1), direction of length (Y1) and diameter of length (D1) but dimension increases in the direction of length (Z1). This methodology not only provides a detailed explanation of the complex building mechanism but also offers insights into how process parameters influence output responses, particularly in terms of part quality. By systematically examining these interactions, it allows for a better understanding of the factors that contribute to the final product's characteristics and performance. From main effect plot results it is concluded that, infill percentage, layer thickness, infill pattern design, & layer thickness affect the part accuracy for the case of length (X1), length (Y1), length (Z1), & length (D1) respectively. Result clearly shows that the Taguchi design method give optimize process parameter setting for each quality characteristic of 3d printed part. goals.

Authors Contribution

Shweta Mishra conceived and designed the study, analyzed the data, and wrote the manuscript. Dr. Mohd Anas supervised the research, provided guidance throughout the study, and critically reviewed the manuscript. All authors reviewed and approved the final version of the manuscript.

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Conflicts of Interests

There are no financial or non-financial conflicts of interest that could influence the interpretation of the research findings or bias the content of this manuscript.

Data Availability Statement

The data used in this study were obtained from various sources. The primary sources of data included Google Scholar for accessing academic literature, books related to additive manufacturing, and journals, the college library for reference materials.

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