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A Review Paper On Current Research And Future Anticipation For Improvement of FDM Process Parameters

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Abstract: Fused deposition modeling (FDM) is one of the most popular additive manufacturing technologies for various engineering applications. The quality of FDM processed components mainly depends on deliberately selection of process variables. Thus, identification of the FDM process parameters that significantly affect the quality of FDM processed components is consequential. Researchers have explored a number of ways to improve the mechanical properties and part quality utilizing numerous experimental design techniques and concepts. This article aims to review the research carried out so far in determining and optimizing the process parameters of the FDM process. Several statistical designs of experiments and optimization techniques utilized for the tenaciousness of optimum process parameters have been examined. The trends for future FDM research in this area are described.

Keywords: Fused deposition modeling (FDM) Experimental design Additive manufacturing Process parameters Mechanical properties Part quality

1 Introduction

Additive manufacturing technology is an advanced manufacturing technology utilized for fabricating components layer by layer directly from a CAD data file. The process builds objects by integrating material in a layer by layer fashion to engender a three-dimensional part, offering the benefit to engender any complex components with shorter cycle time and lower cost compared to traditional manufacturing process. Additive manufacturing technology is widely utilized in engineering for customized products, functional models, pre-surgical models and conceptual models. This technology is finding its applications in many fields of engineering and industry, such as aircraft, dental renovations, medical implants and automotive products. With incremented competition in the world economy, designers and engenderment engineers face the challenge of engendering products more expeditiously than ever to meet customer requisites and achieve competitive edge. Additive manufacturing process offers an efficient technique of building perplexed geometry to minimize the design and engenderment cycle time at the lowest cost due to the absence of any tooling needs [1–6]. FDM has been widely utilized in additive manufacturing technology that provides functional prototypes in various thermoplastics due to its ability to engender complex geometrical components orderly and safely in an office-cordial environment.

This paper presents a comprehensive review of FDM process parameter optimization involving statistical design of experiments (DOEs) and optimization techniques, and identifies several research gaps where further research and development work can be directed to make this technology distribute products with higher precision, better quality and desired properties.

2 Research on FDM process optimization

FDM process conditions play a consequential role in improving surface roughness, dimensional precision, mechanical properties, material comportment and build time. Critical process parameters that affect the quality of processed part have been discussed. There has been extensive research on this topic fixating on experimental results and process optimization. Most of the researches on FDM process parameters have been directed toward optimizing process parameters to amend the surface finish, dimensional precision and mechanical properties for ABS processed components[7]. Many researchers have suggested utilizing felicitous statistical designs and optimization techniques to study the effects of process parameters on FDM processed components. In the following subsections, research on each quality characteristic is reviewed in detail.

2.1 Surface roughness

Thrimurthulu et al. [8] used authentic coded genetic algorithm (GA) to develop an analytical model to soothsay the optimum part orientation for surface roughness. The prediction of the developed model was validated and it was in good agreement with the result published earlier. This study concluded that the developed model could be used topredicted the optimum part orientation for any complex freeform surfaces. However, this developed model has the inhibition that it can only prognosticate build orientation but other critical process parameters cannot be predicted by this model.

Horvath et al. [9] conducted a study for amelioration of surface roughness on ABS400 polymer materials utilizing factorial design. In this study, only three process parameters namely model temperature, layer thickness and part fill style were culled. The results showed that the layer thickness played a consequential role in minimizing surface roughness, where the minimum value of surface roughness of 5.83 lm was obtained when the model temperature was 274 LC with the layer thickness of 0.1778 mm and the fill style of fine raster’s. They concluded that high value of model temperature was preferred as it led to smooth surface.

Anitha et al. [10] investigated the effects of some consequential FDM process parameters on surface roughness of ABS prototype. The Taguchi’s design matrix, signal to noise ratio (S/N) and analysis of variance (ANOVA) were utilized in this study. Three process parameters including layer thickness, road width and speed of deposition were considered. This study revealed that the factor having the most consequential influence on the surface roughness was the layer thickness compared to road width and speed. It was withal revealed that there was inverse cognation between layer thickness and surface roughness.

Nancharaiah et al. [11] studied the influences of process parameters such as layer thickness, road width, raster angle and air gap on the surface finish of FDM processed ABS part through Taguchi method and ANOVA technique. It was optically discerned that surface roughness could be ameliorated by utilizing lower value of layer thickness and air gap because it reduced the voids between layers. The impotency of this approach [14, 15] lies in only determining the best combination of process parameters. It cannot be habituated to determine the final optimum process conditions particularly in cases of multi-quality optimization.

Wang et al. [12] utilized a statistical optimization method to investigate the effects of control parameters such as layer thickness, deposition style, support style, and deposition orientations on the surface roughness by integrating the Taguchi method with the gray relational analysis. It was concluded that by utilizing the optimum factor settings, the surface roughness was ameliorated by 62.27%. This study revealed that optimal parameter coalescences of surface roughness were obtained with less number of experimentations utilizing Taguchi method compared to full factorial design which yielded kindred results.

2.2 Dimensional accuracy

Wang et al. [12] additionally pointed out that dimensional precision of fabricated part depended on build orientation and de-positing thickness. The differences in dimensional accuracy in the different building directions were the results of different deposition patterns.

Sood et al. [13] studied the influences of five process parameters including part orientation, road width, layer thickness; air gap and raster angle on dimensional precision of FDM fabricated ABSP400 part utilizing gray Taguchi method. They pointed out that there was shrinkage along the length, width and diameter of the aperture of the fabricated part as the dimensions were less or more than the designed value. However, thickness of the fabricated part was above the desired value. It was concluded that to reduce the deviation between fabricated part dimension and CAD model dimension, layer thickness of 0.178 mm, part orientation of 0L, raster angle of 0L, road width of 0.4564 mm and air gap of 0.008 mm should be utilized. In this study, the optimum process parameters were different for each quality criterion, denoting that the optimum process conditions could not be obtained. Therefore, further work has been done by employing gray relational grade (GRD) to convert three responses into one response. In order to predict these three replications more accurately due to their non-linearity, they used artificial neural network (ANN) and fuzzy logic. After all this work, the best parameter amalgamations were obtained.

Nancharaiah et al. [11] additionally applied Taguchi method and ANOVA technique to identify the key factors that influenced the dimensional precision of deposited ABS components. The input variables such as layer thickness, road width, raster angle and air gap were considered. They concluded that layer thickness and air gap significantly affected the precision of FDM components. However, in this study, optimum settings of layer thickness, road width, raster angle and air gap in the range were not addressed.

Zhang and Peng [14] established empirical cognations between process parameters (wire-width emolument, extrusion velocity, filling velocity, and layer thickness) and dimensional error and deformation of FDM fabricated ABS part utilizing Taguchi method cumulated with fuzzy comprehensive evaluation. They reported that the optimal process parameter values for dimensional error were: wire-width emolument 0.17 mm, extrusion velocity 20 mm/s, filling velocity 30 mm/s and layer thickness 0.15 mm. In case of deformation, the optimum amalgamations of the parameters were: wire-width emolument 0.17 mm, extrusion velocity 25 mm/s, filling velocity 20 mm/s and layer thickness 0.30 mm. In this study, other sundry process parameters were not considered. Only the best cumulation of the culled process parameters was obtained. Further-more, if the goal was to minimize both dimensional error and deformation together, the study could not provide a definite answer in terms of ecumenical solution to this quandary.

Sahu et al. [15] applied Taguchi method to study the main and interaction effects of process variables such as layer thickness, orientation, raster angle, raster width and air gap on part precision. In this study, presage model predicated on fuzzy logic and Mamdani method was developed to optimize dimensional precision. It was concluded that the value of average percentage error of less than 4.5% was obtained from the laboratory experiment which concurred well with the soothsaid replication. However, the utilization of fuzzy inference system (FIS) requires developing rules. Therefore, it requires congruous expertise cognizance and experience.

2.3 Material behavior

Lee et al. [16] performed experimental investigation on optimization of rapid prototyping parameters for produc-tion of flexible ABS object. They carried out Taguchi method and ANOVA technique considering air gap, raster angle, raster width and layer thickness as parameters. The study concluded that layer thickness, raster angle and air gap were the critical factors in determining the elastic performance of the component. The optimum parameters deter-mined and the results obtained were in a good acquiescent with the laboratory experiments with error percentage of 0.18%.

Laeng et al. [17] found the effects of air gap, raster angle, raster width and layer thickness on the elasticity performance of ABS material for FDM by utilizing Taguchi method and ANOVA procedure. Predicated on their study, the optimum cumulations of process parameters were obtained for ameliorating overall elasticity performance. How-ever, the optimal settings are restricted to the experimental values only, where, in fact, the optimal settings are not precisely equipollent to the parameters' values. Thus the optimal parameter settings cannot be obtained utilizing this approach. It can be obtained utilizing replication surface methodology (RSM) and empirical optimization techniques.

Zhang and Chou [18] optically canvassed relating process parameters to stress distribution and part distortions. They developed a finite element model to evaluate the stress distribution and part distortions at different deposition conditions. Central composite design (CCD) and ANOVA were habituated to establish the correlation between process parameters and residual stresses and part distortions in FDM process. Road width, layer thickness, and scan speed were culled as main parameters. It was reported that layer thickness was the key factor that affected the residual stresses and part distortions. The study concluded that the residual stresses and part distortions incremented with layer thickness and road width during the deposition stage. The main aspect in this study was that the finite element model developed was in good acquiescent with the experimental result with a minute error. However, a constraint of this study was that a amalgamated parameter setting could not simultaneously satiate all the objectives.

2.4 Build time

Thrimurthulu et al. [8] withal presented a mathematical model to presage and optimize the build time. They considered build orientation as the most consequential process variable that affected the build time. From the results, optimum build orientation was obtained utilizing an authentic coded GA. They compared the predictive capabilities of the models developed with other published works. It was pellucid that the proposed model was in plausible accedence with the result published earlier.

Kumar and Regalla [19] applied 25 full factorial design to analyze the influence of each process parameter, such as layer thickness, raster angle, orientation, contour width and part raster width on support material volume and build time of FDM part. It was experimentally reported that the layer thickness and build orientation were consequential factors in the minimization of the build time. However, the study did not fixate on the optimum process settings that minimize the build time and support material volume.

Nancharaiah [20] examined the relationship between process parameters and build time utilizing Taguchi's design matrix L9 orthogonal array and ANOVA technique. It was pointed out that process parameters such as layer thickness and air gap could affect the build time significantly. It was additionally reported that the layer thickness and air gap contributed 66.57% and 30.77% respectively on the build time. The results withal revealed that layer thickness of 0.330 mm, air gap of 0.020 mm and raster angle of 30L were the optimum parameters to reduce thebuild time. Nevertheless, optimum conditions for the objectives were not given.

2.5 Mechanical properties

2.5.1 Static mechanical properties

Ahn et al. [21] experimentally investigated the effects of FDM parameters and build orientation on the tensile vigor and compressive vigor of the ABS components processed by FDM. Varied parameters in the experiments were air gap, road width, model temperature, material color and build orientation. For the purport of determining the effects of the process parameters on the mechanical properties, a 25 full factorial design was utilized. They concluded that by utilizing optimum process parameters, the tensile vigor and the compressive vigor of the ABS part were in the ranges of 65%–72% and 80%–90%, respectively.

Ang et al. [22] revealed that the mechanical properties and porosity of ABS manufactured components were mostly influenced by process conditions such as air gap, raster width, build orientation, build laydown pattern and build layer. They used 25 fractional factorial design to under-stand the influence of each process variable. They reported that air gap had the most sizably voluminous effect on the porosity and mechanical properties of the scaffolds. Predicated on their study, multiple regression models were acclimated to check the significant amendment of mechanical properties and porosity. In this work, the effects of some variables on mechanical properties were studied, and resoluteness of optimum settings was not considered.

Wang et al. [12] found that tensile vigor of FDM part was significantly higher when testing samples were put in the deposition orientation—Z direction. They demonstrated that the worst tensile vigor was observed when testing samples were in the direction perpendicular to the layer. The developed model was verified experimentally and the presaged results acceded well with laboratory experiments. However, they obtained the three independent optimum solutions, for the minimum dimensional deviation, the minimum surface roughness, and the maximum tensile vigor, respectively. If the dimensional deviation and surface roughness should be as minimum as possible, and at the same time the tensile strengthshould be maximized,the paper could not provide a conclusive answer and overall solution to this quandary.

Sood et al. [23] developed a mathematical model to optimize the mechanical properties of FDM components utilizing the following input variables: layer thickness, build orientation, raster angle, raster width and air gap. CCD and ANOVA were employed. This study concluded that by incrementing the layer thickness, less number of layers were required. This reduced residual stress and deformation in the component, and amended part vigor through ameliorating part resistance. It was additionally concluded that minuscule raster angle was not preferred as minute raster angle would increment residual stress and deformation, hence it would debilitate bonding vigor. It was observed that thick raster and zero air gap ameliorated the mechanical properties.

Percoco et al. [24] investigated the influences of the chemical treatment on the compressive vigor and mechanical deportment of treated FDM prototypes. This study investigated the effects of three process parameters including raster width, raster angle and immersion time on compressive vigor utilizing CCD. The results showed that in terms of untreated specimens (non-culminated components), raster angle had a very low influence on the compression vigor. The results withal revealed that the compressive vigor incremented with the incrementation of raster width. They concluded that the immersion time of up to 300 s could be acclimated to decrement roughness by up to 90%, making mechanical properties better than untreated components.

Masood et al. [25] experimentally investigated the effects of the FDM process parameters such as build style, raster width, and raster angle on the tensile properties of PC FDM. They concluded that the highest tensile vigor could be obtained when build style was solid mundane, raster width was 0.6064 mm and raster angle was 45L. It was additionally concluded that the tensile vigor of PC prototype greatly depended upon build style because the solid mundane build style filled the component consummately with plenarily dense raster implement paths. This study withal concluded that PC material had goodtensile vigor ranging from 70% to 80% of the injection molded PC components.

Rayegani and Onwubolu [26]. It was an advanced learning on experimental investigation and optimization of FDM process parameters on tensile vigor utilizing full factorial design, group method of data handling (GMDH) and differential evolution (DE). Build orientation, raster angle, raster width and air gap at two levels were considered as parameters. The optimum process parameters were obtained to maximize tensile vigor, and the study reported that maximum tensile vigor could be obtained when the build orientation was at 0L, rasterangle at 50L, withthe raster width of 0.2034 mm andnegative air gap of0.0025 mm.

2.5.2 Dynamic mechanical properties

In additament to static loading conditions, FDM manufactured components are withal subjected to the dynamic and cyclic loading conditions such as in vibrating machinery and transportation applications. Very few studies have been conducted on understanding the demeanor of FDM components subjected to such loading conditions.

Jami et al. [27] experimentally investigated the influences of three different build orientations on high-strain-rate dynamic replication of ABS components manufactured by FDM utilizing a split Hopkinson pressure bar. Three different build orientations, vertical on X–Y plane parallel to Z-axis, horizontal at 0L to X-axis and horizontal at 45L to X-axis were considered. From the experimental results, it was demonstrated that the build orientation, which was vertical on X–Y plane parallel and horizontal at 45L to X-axis resulted in higher modulus of the component. They withal found that there was no influence of build orientations on the stress strain replications under quasi-static conditions. However, build part orientation has an effect on dynamic replication of the FDM fabricated components. It was reported that ABS part made by FDM had the ability to be an efficacious material under quasi-static and high-strain-rate conditions.

Arivazhagan et al. [28] investigated the effects of the FDM process parameters such as build style, raster width, and raster angle on the dynamic mechanical properties of PC processed part. Frequency sweep from 10 Hz to 100 Hz was utilized at three different isothermal temperatures. It was concluded that solid mundane build style with raster angle of 45L, and the raster width of 0.454 mm led to the best dynamic properties than other build styles (double dense and sparse).

Arivazhagan and Masood [29] presented experimental investigation on dynamic mechanical properties but with ABS part fabricated by FDM. They observed that solid mundane build style provided higher modulus than double dense and sparse build styles. It was experimentally reported that with incrementing temperature, the loss modulus incremented. However, storage modulus and viscosity decremented with the incrementation of temperature.

However, the inhibitions of the work in Refs. [25–29] lie in studying the relationships between FDM process variables and mechanical properties of fabricated components without utilizing scientific methods such as DOE and optimization techniques. The disadvantage of this approach is that it may lead to erroneous optimal results because the interactions between factors identifying their consequentiality to the output replication and best settings of these variables cannot be tenacious. Therefore, for practical applications, theseinteractions and best settings of processing parameters need to be estimated.

3 Results and discussions

After reviewing the published literature, it is pellucid that optimization of process parameters of FDM additive manufacturing technology is one of the most critical design tasks in quality evaluation designators for obtaining high quality components, enhanced material replication and enhanced properties. There are many variants of FDM machines available in the market. These machines differ in size, build speed, type of material, build volume and range of process parameter settings. To understand the mechanical properties and material demeanor of FDM components, the effects of the process parameters on the quality characteristic of the components must be studied more exhaustively. A summary of published work on optimization of FDM process parameters utilizing DOE method to investigate the effects of sundry process parameters on the outputs is presented in Table 1.

Table 1 denotes that sundry statistical optimization methods have been widely used to study the process conditions of FDM rapid prototyping process. The applications of the Taguchi method and ANOVA procedure are found to be ascendant among those optimization techniques. However, Taguchi method can only determine the best cumulation of calibers of process variables and the interaction effects [30]. From Table 1, it is observed that the critical process parameters are identified utilizing the ANOVA procedure. These consequential input parameters are air gap, layer thickness, raster angle, raster width and build orientation. However, some published works in optimizing process parameters have not evaluated the lack-of-fit (LOF) in their experiments which perhaps designated that the model was not fit for all the design points well. In this case, the experimental design probably needs to be ex-inclined with more runs to estimate the interactions in more precise way.

Predicated on the literature review, it is pellucid that several optimization techniques such as RSM, Taguchi method, full factorial, gray relational, fractional factorial, ANN, fuzzy logic and GA have been utilized for optimizing FDM operating parameters. Table 2 shows an overview of DOE utilized for optimization of FDM process parameters. Taguchi method is an efficacious implement for optimizing FDM process parameters. Taguchi method provides simple, reliable and efficacious approach in practical applications to amend the product quality at low cost. It is noted that the Taguchi method can reduce the number of experiments significantly in comparison with RSM [31]. In Taguchi method, optimum parameter settings can be tenacious utilizing different

Table 1 Summary of published work on FDM process optimization [7]

References	Methods	Materials	Inputs	Outputs	Significant inputs
Thrimurthulu et al. [8]	GA	ABS	Slice thickness, build deposition orientation	Surface finish and build time	All input parameters
Horvath et al. [9]	2^3 and 3^2 full factorial designs	ABS	Model temperature, layer thickness, part fill style	Surface roughness	Layer thickness
Anitha et al. [10]	Taguchi method, (S/N) & ANOVA procedure	ABS	Layer thickness, road width, speed of deposition	Surface roughness	Layer thickness
Nancharaiah et al. [11]	Taguchi method, ANOVA procedure	ABS	Layer thickness, road width, raster angle, air gap	Surface quality and dimensional accuracy	All input parameters
Wang et al. [12]	Taguchi method, ANOVA along with gray relational analysis	ABS	Layer thickness, deposition style, support style, deposition orientation	Tensile strength, dimension accuracy and surface roughness	Layer thickness and deposition orientation
Sood et al. [13]	Gray Taguchi method, ANN	ABS	Part orientation, road width, layer thickness, air gap, raster angle	Dimensional accuracy	Build orientation
Zhang and Peng [14]	Taguchi method	ABS	Wire-width compensation, extrusion velocity, filling velocity, layer thickness	Dimensional error and warpage deformation	All input parameters
Sahu et al. [15]	Taguchi method, fuzzy logic	ABS	Layer thickness, orientation, raster angle, raster width, air gap	Dimensional accuracy	All input parameters
Lee et al. [16]	Taguchi method, ANOVA procedure	ABS	Air gap, raster angle, raster width, layer thickness	Elastic performance	Air gap, raster angle and layer thickness
Laeng et al. [17]	Taguchi method, ANOVA procedure	ABS	Air gap, raster angle, raster width, layer thickness	Elastic performance	Air gap, raster angle and layer thickness
Zhang and Chou [18]	Finite element analysis, CCD & ANOVA	ABS	Scan speed, layer thickness, road width	Residual stresses and part distortion	Scan speed, layer thickness
Nancharaiah [19]	Taguchi's design, ANOVA procedure	ABS	Layer thickness, air gap, raster angle	Production time	Layer thickness, air gap
Kumar and Regalla [20]	2^5 full factorial design, ANOVA procedure	ABS	Layer thickness, raster angle, orientation, contour width, part raster width	Support material volume, build time	All input parameters
Ahn et al. [21]	2^5 full factorial design	ABS	Air gap, raster orientation, bead width, raster width, model temperature, color	Tensile strength, compressive strength	Air gap, raster orientation
Ang et al. [22]	2^5 full factorial design	ABS	Air gap, raster width, build orientation, build laydown pattern, build layer	Porosity, compressive yield strength, compressive modulus	All input parameters
Sood et al. [23]	CCD, ANOVA procedure	ABS	Layer thickness, orientation, raster angle, raster width, air gap	Tensile, flexural and impact strength	All input parameters
Percoco et al. [24]	CCD	ABS	Raster width, raster angle, immersion time	Compressive strength	Raster width
Masood et al.[25]	Laboratory experiment	PC	Build styles, raster angle, raster	Tensile strength	**Not applicable**
Rayegani and Onwubolu [26]	2^4 full factorial design, GMDH & DE	ABS	Part orientation, raster angle, raster width, air gap	Tensile strength	All input parameters

Jami et al.[27]	Laboratory experiment	ABS	Build orientations	High-strain-rate behavior	**Not applicable**
Arivazhaganet al. [28]	Laboratory experiment	PC	Build styles, raster angle, rasterwidth	Storage modulus, complexviscosity	**Not applicable**
Arivazhaganand Masood[29]	Laboratory experiment	ABS	Build styles, raster angle, rasterwidth	Storage modulus, complex viscosity	**Not applicable**

Table 2 Comparison between the common experimental designs and optimization techniques

Capability	**Techniques**							
	Taguchi method	**GA**	**Fuzzy logic**	**Gray relational**	**ANN**	**GMDH**	**Factorial Design**	**RSM**
Understanding	Normal	Difficult	Difficult	Normal	Moderate	Moderate	Easy	Moderate
Multi-response optimization	×	√	√	√	√	√	×	√
Uses	Widely	Rarely	Rarely	Widely	Widely	Rarely	Widely	Widely
Shape of the experimental Region	Regular or irregular	Regular or irregular	Regular or irregular	Regular or irregular	Regular orirregular	Regular orirregular	Regular	Regular
Computational time	Short	Very long	Very long	Short	Long	Medium	Short	Short
Prediction accuracy	Low	High	High	Normal	Very high	High	Normal	Very high
Models linear dynamics	√	√	√	√	√	√	√	√
Developing of mathematical model	×	×	√	×	√	√	√	√
Data requirement for a given output	Mid	High	High	Mid	High	High	Mid	Low
Optimal solution	Straight	Straight	Through model	Straight	Through model	Through model	Straight	Through model
Ability to study interaction effects between variables	√	×	×	√	×	×	√	√
Availability in simulation software	√	√	√	√	√	√	√	√

signal to noise ratios, depending on the goal of experiment. However, in Taguchi method, two-factor interactions are confounded with other two factors and higher interactions, which leads to non-optimal ecumenical solution. The presage models cannot be developed and they are not congruous in advanced manufacturing process such as FDM due to the desideratum of multiple-replication quality criteria and high quality of fitting models.

The RSM is considered to be a more promising method for optimization as it gives very low standard error towards experimental verification. The most paramount replication surface methods used frequently are the CCD and Box-

Behnken design. It can be noted that RSM is a potent optimization design in achieving the optimal solution of the quandary because this method provides the ability to deal with higher degree of fitting models and multi-objective optimization in cases that are required to optimize more than one replication (as in FDM process parameters). In additament, RSM is more puissant in identifying the critical process parameters, the main effects and interaction effects of parameters which provide enough information for experimental studies [32]. Furthermore, consequentiality of interactions and square terms of variables are more limpidly prognosticated in RSM. However, in the case of quandaries with sizably voluminous number of process parameters, the experiments may be time-consuming in comparison with Taguchi design, as shown in Table 2.

Full factorial design is another method which sanctions the investigator to study the influences of process parameters on the replication outputs. The main effects and all higher-order interactions for process parameters can be estimated. The main constraint with a full factorial design is that more experimental runs are required to achieve better precision and reduce percentage of error [32, 33]. Therefore, for most of the experiments, particularly in advanced manufacturing process such as FDM, it is time-consuming and expensive. For these reasons, researchers prefer to utilize fractional factorial design than full factorial design, as it requires less number of runs. But the main disadvantage of having a minimum number of experimental runs is that two-factor interactions will be confounded with interactions among three or even more factor interactions, which cannot be distinguished from each other. Thus, optimum process settings cannot be resolute accurately.

In regard to the gray relational analysis, the researchers often utilize this method for quantifying the relationship between process variables. However, from the literature review, it can be noted that in practical situation, tenaciousness of an optimal set of process variables could be very slow and the interactions between some effects may confound with other factors.

The literature review presented in anterior section designated that the empirical optimization techniques were utilized for optimizing process parameters of FDM rapidprototyping. ANN is the most popular empirical modelling applied to express the mathematical relationship between the process parameters and quality characteristics. It was utilized in the case when the relationship between input parameters and output was unknown. It has the ability to identify involute non-linear relationships between process parameters and output [34, 35]. This empirical technique however cannot be retrained in the case of integrating data to a subsisting network. Furthermore, ANN does not provide enough information about factors and their effects on the output replication if further analyses utilizing screen experimental designs such as Plackett-Burman or full factorial ones have not been done. GA is another method of the empirical modeling used to optimize the process variables. GA is utilized to solve quandaries with multiple objectives and it is very facile to understand by the rapid prototyping practitioners without desideratum of deep mathematics erudition [36]. Through GA, however, variant quandaries cannot be solved due to poor fitness functions. It is noted that the main ad-vantage of fuzzy logic is that it does not require training data compared to ANN. However, fuzzy logic approach requires developing rule and database. Thus, rapid prototyping practitioners must have in-depth cognizance of mathematics. Moreover, fuzzy logic requires a substantial amount of data storage, which may decelerate the process.

4 Research gap, problem and challenge

Different process parameters have effects on the component quality of FDM. Essentially, the quality characteristics of FDM build part such as flexural strength, hardness, tensile strength, compressive strength, dimensional precision, surface roughness, engenderment time, yield strength and ductility are the primary concerns to the manufacturers and users. Recent years, research has been targeting into identifying the optimal process parameters to ameliorate surface finish, aesthetics, mechanical properties, model material consumption and build time. However, there are still no impeccable optimal conditions for all types of components and materials. For most components, there is always a desideratum to adjust parameters to balance a tradeoff between engenderment time, surface finish, and dimensional precision. The properties of the FDM fabricated components can be controlled by the culled build styles and other FDM parameters. FDM processed components mundanely have lower mechanical properties and surface finish than the components made by conventional manufacturing process such as injection moulding. To improve the component quality and mechanical properties for FDM fabricated components, it is indispensable to understand the relationship between material properties and process parameters.

The literature review designates that much research work has been endeavored to amend the mechanical properties and part quality for FDM fabricated ABS components by optimizing one or several consequential process parameters. From anterior studies, it has been shown that the quality of FDM built part is highly affected by sundry process variables. Hence, the identification of the critical process parameters and tenaciousness of optimum process parameters can lead to the quality amendment of FDM fabricated part. However, the relationships between the process parameters and the component quality and mechanical properties have not been studied enough especially for sundry types of materials utilized by the FDM process.

In terms of material properties, most of the studies are mainly fixated on optimizing the process parameters for mechanical properties of ABS components. However, there have been no published research articles relating to the reinforcement of FDM material. Therefore, much research work is needed in this area in the future research.

Effects of process parameters on surface roughness, tensile strength, compressive strength, flexural, impact strength and dimensional precision have been studied. But the study needs to be elongated to other types of quality characteristics such as hardness, engenderment time, creep, vibration, product and process cost, porosity and stress strain comportment at high-strain-rate loading conditions.

5 Conclusions

This article presents a review of research work carried out in the tenaciousness and optimization of the process parameters for FDM. This article withal outlines the directions for future FDM research. A number of research works predicated on sundry optimization techniques were reviewed including RSM, Taguchi method, full factorial, gray relational, fractional factorial, ANN, fuzzy logic and GA. A review of research work on sundry optimization techniques designated that there were prosperous industrial applications of Taguchi method, RSM, GA and ANN. The paper has withal identified several critical areas of future research in optimizing and characterizing the FDM process and FDM materials. It has accentuated that FDM is characterized by an immensely colossal number of process variables that determine the mechanical properties and quality of fabricated components. Much research work has been endeavored to ameliorate the mechanical properties and part quality for FDM fabricated ABS components through statistical design optimization. How-ever, modeling and optimization of FDM process with other FDM materials such as composite material (insertion of layer in ABS) etc., have not been undertaken. Furthermore, characterization and optimization of FDM process parameters in terms of other properties through incipient statistical experiment design and optimization techniques are additionally non-existent in the literature. These future works will provide a wealth of cognizance in making the FDM process an ideal additive manufacturing process for engineering applications with high part quality, precision and desired opportune-ties. Overall literature review shows that process parameters including air gap, layer thickness, raster angle, raster width and build orientations are the critical factors and these must be studied and analyzed in future research.

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