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On processing of PVC-PP-Hap Thermoplastic Composite Filaments For 3D Printing In Biomedical Applications

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Abstract
Additive manufacturing (AM) or 3D printing technology is one of the fast-growing fabrication processes in different manufacturing sectors. For 3DP, by using the fused deposition modeling (FDM) process, feedstock filament is to be used as input materials for the fabrication of any model, scaffolds, or any other things. In this research work, feedstock filament has been fabricated by reinforcement of hydroxyapatite (HAp) powder in PVC and PP thermoplastic polymers by using twin-screw extruder (TSE) based upon Taguchi L18 orthogonal array (OA). After the fabrication of feedstock filament using TSE, tensile testing has been performed on a universal tensile tester (UTT). The modulus of toughness has been calculated using output values from tensile testing. In this experimental research work, the best input setting of the extruder for the preparation of feedstock filament is to be obtained using Taguchi L18 OA, and on best setting confirmatory experimentation has been performed. Finally, based upon this experimental work shows the best parametric conditions for modulus of toughness have obtained at the parametric combination of 96Q+4, 50rpm, 200°C, 106 µm, and 20 kg load.

Keywords: *Feed stock filament, Tensile strength, Taguchi L18, PVC polymer.*

Abbreviations

PVC	Polyvinyl Chloride
TSE	Twin-screw extruder
HAp	Hydroxyapatite
PP	Polypropylene
UTT	Universal tensile tester

I. Introduction

Polymers or polymer-based materials have one of the most demandable and necessary parts of the developed and modern society [1]. Thermoplastic polymers have lots of advantages over glass-based materials and traditional metals as per their applications, such as; easy availability, easy of use/processing, and low cost [2].

Thermoplastics can be more than once relaxed and reshaped upon the utilization of heat without influencing their innate properties [3]. Some of the most important properties of thermoplastic polymers are very effective such as; high reforming ability, easy recyclability, chemical resistance, and high impact resistance [1]. Due to these distinct properties, thermoplastic polymers have a very high range of applications which include biomedical application, storage, and packaging of materials[4]–[6], automotive, machine parts, and consumer goods [7].

PVC thermoplastic polymer is very versatile and economical that has been widely used in the structural and civil industry works to produce door, medical devices, and cable insulation [8]. PVC is a transparent or white and solid brittle material[9]–[11] available in granules form and white in powder form [12]. Because of its flexible properties, for example, lightweight, solid, minimal effort, and simple processability, PVC is currently supplanting customary structure materials like solid, elastic, wood, metal, pottery, and so forth in a few applications [2]. Plasticizers are mainly used for enhancing of rheological and mechanical performance of PVC thermoplastic polymer [3]. Some good fillers (Glass, titanium dioxide, talc, calcium carbonate, calcined clay) are added in PVC polymer for enhancing mechanical and thermal strength, stiffness and improve its performance [13][14].

In this experimental work, an effort has been made to the fabrication of the feedstock filament of thermoplastic polymer (PVC polymer) is reinforced with PP polymer for enhancing the mechanical hardness of fabricated feedstock filament, and HAp powder has been mixed for enhancing bioactive properties. This study is an extension of previous work [14]. In the previous work, feedstock filament has been prepared using TSE by reinforcement of PVC-PP-HAp, and mechanical properties have been checked by using Minitab software (Taguchi L18 orthogonal array (OA)) and UTT [15], [17]. In this present study, the Modulus of toughness has been determined by using Minitab software (Version 18.0) for the fabrication of feedstock filament with a better modulus of toughness on TSE.

II. Experimentation

This is the extension of the previous research work. In this experimental work, feedstock filament has been fabricated according to Taguchi L18 ($2^{x}1$ $3^{x}4$) OA. For fabrication of best feedstock filament according to mechanical/tensile strength some input parameters and their different level has been selected that has been shown in Table no.1., no. of input parameters and their different levels (based upon previous research work and pilot experimentation) are shown for the experimental work. Based upon Table 1 control log of experimentation has been prepared using Taguchi L18 (2^x1 3^x4) OA with a total of 18 sets of experiments.

Table1. Different input parameters and their levels based on Taguchi L18 OA.

Levels	*Materials*	*Rotational Speed of screw*	*Barrel Temperature for extrusion*	*The grain size of Hap reinforcement*	*Forced Loading*
1	96Q%+4%	30 rpm	180°C	53 µm	10 kg
2	92Q%+8%	40 rpm	190°C	106 µm	15 kg
3	--	50 rpm	200°C	150 µm	20 kg

Note; *Q: - 70% of PVC polymer& 30% of PP polymer*

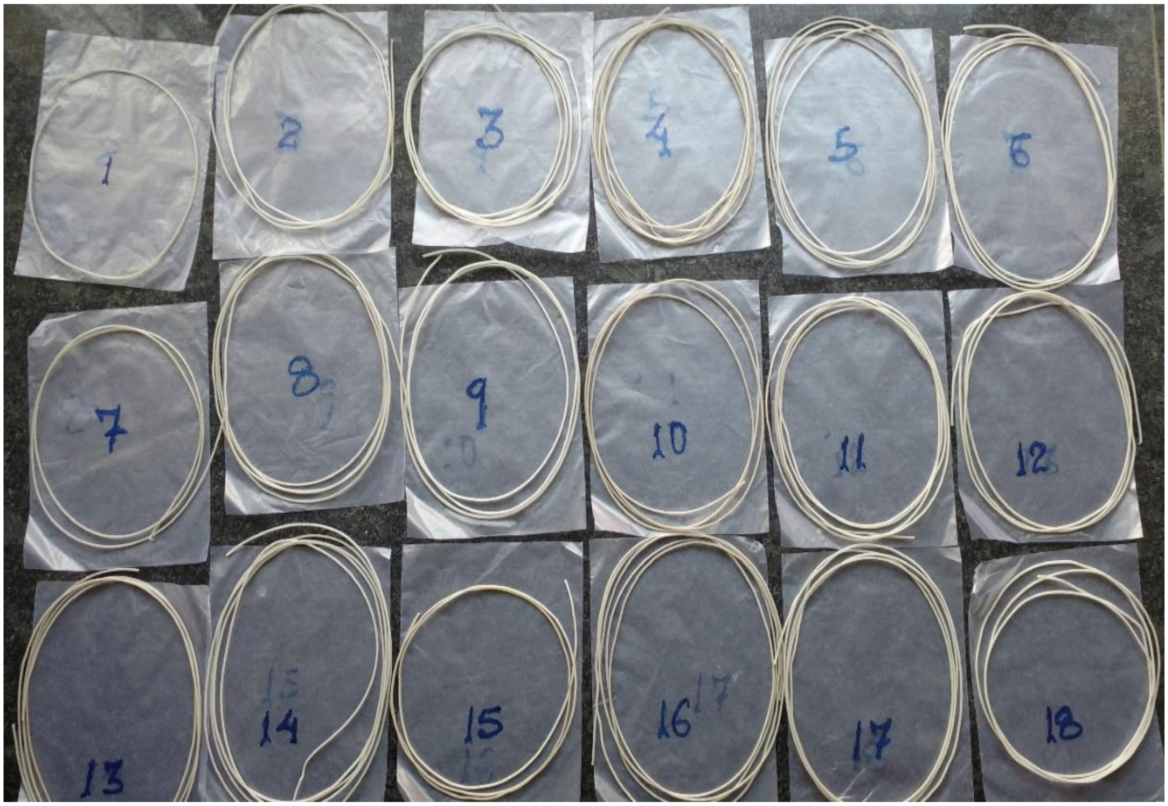

Fig. 1. PVC-PP-HAp based fabricated feedstock filament using Taguchi L18 OA [14]

Based on Table 1 control log of experimentation has been designed that is shown in Table 2, and fabricated feedstock filament-based upon control log of experimentation has been prepared and shown in Fig. 1.

III. Result and Discussion

Table 2 shows the different set of experiments by varying the input process parameters as per Taguchi L18 (2^1 3^4) OA and output values for tensile strength (strength at the peak, percentage elongation at the peak, percentage elongation at break, and modulus of toughness) of fabricated feedstock filament by reinforcement of PVC and PP thermoplastic polymers and Hap. The modulus of toughness has been calculated by the values of stress and strain. The modulus of toughness provides the object to resist the crash loading.

Table 2. Control log of experimentation and output result of feedstock filaments

Exp. No.	*Composition of Materials*	*Rotational Speed*	*Temperature*	*The grain size of HAp*	*Load*	*Strength at the peak of filaments (MPa)*	*%age elongation at the peak of filaments*	*%age elongation at break of filaments*	*Modulus of the toughness of filaments (MPa) (0.5×stress ×strain)*
1	96Q+4	30 rpm	180°C	53μm	10 kg	9.04	3	4	0.1808
2	96Q+4	30 rpm	190°C	106μm	15 kg	8.64	3	4	0.1728
3	96Q+4	30 rpm	200°C	150μm	20 kg	8.06	5	6	0.2418
4	96Q+4	40 rpm	180°C	53μm	15 kg	7.31	4	5	0.1828
5	96Q+4	40 rpm	190°C	106μm	20 kg	5.98	4	5	0.1495
6	96Q+4	40 rpm	200°C	150μm	10 kg	9.24	4	5	0.2310
7	96Q+4	50 rpm	180°C	106μm	10 kg	9.26	4	6	0.2778
8	96Q+4	50 rpm	190°C	150μm	15 kg	7.31	4	4	0.1462
9	96Q+4	50 rpm	200°C	53μm	20 kg	9.39	6	11	0.5165
10	92Q+8	30 rpm	180°C	150μm	20 kg	6.72	6	11	0.3696
11	92Q+8	30 rpm	190°C	53μm	10 kg	5.6	3	3	0.0840
12	92Q+8	30 rpm	200°C	106μm	15 kg	7.31	5	7	0.2559
13	92Q+8	40 rpm	180°C	106μm	20 kg	4.6	5	7	0.1610
14	92Q+8	40 rpm	190°C	150μm	10 kg	4.21	3	4	0.0850
15	92Q+8	40 rpm	200°C	53μm	15 kg	5.58	5	9	0.2511
16	92Q+8	50 rpm	180°C	150μm	15 kg	4.01	3	7	0.1404
17	92Q+8	50 rpm	190°C	53μm	20 kg	6.33	8	9	0.2849
18	92Q+8	50 rpm	200°C	106μm	10 kg	7.51	8	14	0.5257

Note*; Q: - 70% of PVC polymer & 30% of PP polymer*

As observed from Table 2, experimentation run no.18are highest obtained value of modulus of toughness on the experimental setting with the composition of materials is 92Q+8 at 50 rpm and working temperature 200°C with a grain size of HAp is 106µm with the applied load as 10kg. The sample of experiment no. 11 has been obtained with a minimum modulus of toughness, and the filament processing condition was noted as 92Q+8 materials combination at 30 rpm and working temperature of 190°C with 53µm of grain size of HAp and applied load was 10kg.

Table 3.Analysis of Variance for SN ratios

parameters	*DF*	*Seq SS*	*Adj SS*	*F*	*P*	*Percentage contribution*
Composition of materials for filaments	1	2.293	2.293	0.11	0.729	0.68
Rotational speed	2	72.049	72.049	3.60	0.111	21.42
Temperature	2	170.580	170.580	8.52	0.016	50.71
Grain size of HAp	2	19.276	19.276	0.97	0.520	5.73
Load	2	40.734	40.734	2.04	0.247	12.11
Residual Error	8	31.476	31.476			9.35
Total	17	336.407				

As shown in Table 3, the residual error is found 9.35%, which is acceptable at a 90% confidence level. The percentage contribution of the input process parameters has been observed at 21.42%, 50.71%, and12.11%, respectively, whereas the composition of materials & grain size of HAp is the least significant with less percentage contribution 0.68&5.73respectively. Fig. 2 shows the predicted parametric setting for maximizing the modulus of toughness. The predicted setting for maximizing the SN ratio has been calculated like the setting of 96Q+4 material combination, 50 rpm rotational speed, 200°C barrel temperature, 106-grain size of Hap, and 20Kg forced loading.

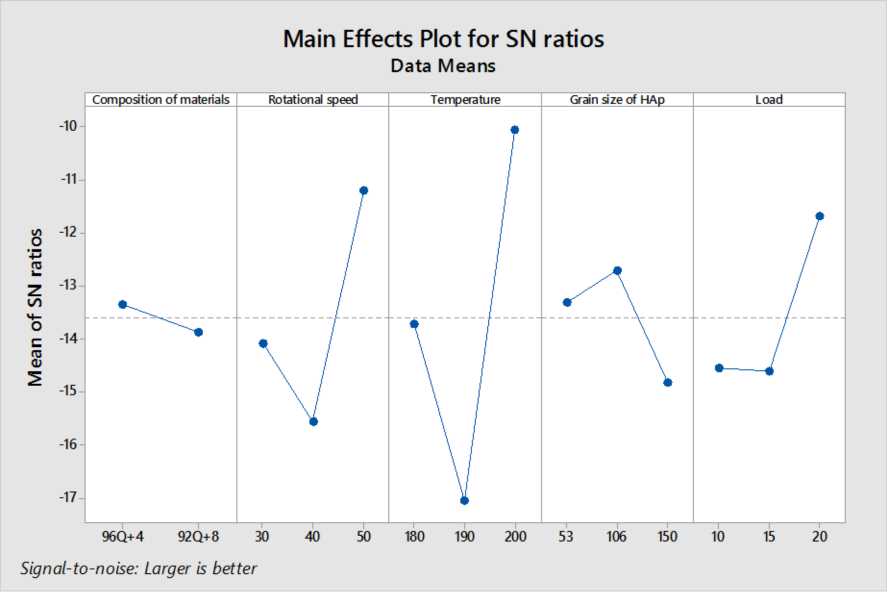

Fig. 2 Main effect plots for SN ratios for Modulus of toughness

Table 4 is the response of the SN ratio for the modulus of toughness. The calculation of the delta value resulted in the ranking of process parameters. It has been observed as per delta value that barrel temperature has been ranked 1, followed by rotational speed ranked 2, forced loading ranked 3, the grain size of Hap ranked 4, and composition of materials ranked 5. This means, for extrusion, the barrel temperature should be considered as the most critical parameter.

Table 4. Response Table for Signal to Noise RatiosLarger is better

Level	Composition of materials	Rotational speed	Temperature	The grain size of HAp	Load
1	-13.33	-14.07	-13.72	-13.30	-14.54
2	-13.87	-15.55	-17.05	-12.69	-14.60
3		-11.18	-10.04	-14.81	-11.67
Delta	0.54	4.36	7.01	2.12	2.94
Rank	5	2	1	4	3

For optimization of modulus of toughness results, an SN ratio-based model has been used for the calculations. The η_{opt} is the optimum SN ratio, m is the mean of SN ratio of 18 different experiments, m_{A1} is the materials combination of level 1, i.e., 96Q+4, m_{B3} is the rotational speed at level 3, i.e., 50rpm, m_{C3} is the barrel temperature at leve 3, i.e., 200°C, m_{D2} is the grain size of Hap at level 2, i.e., 106 and m_{E3} is the forced loading at level 3, i.e., 20 rpm.

$\eta_{opt} = m+(m_{A1}-m)+(m_{B3}-m)+(m_{C3}-m)+(m_{D2}-m)+(m_{E3}-m)$

Further, the optimum value of modulus of toughness (y_{opt}) has been calculated by the following expression.

$y^2_{opt} = (10)^{\eta_{opt}/10}$

Based upon peak values in Fig.2, the confirmatory experiment for modulus of toughness is conducted for 96Q+4, at 50 rpm, 200°C temperature with the 106μm grain size of HAp and 20kg load applied. The observed value was 0.5783 MPa.

IV. Conclusions

From this current experimental research work, conclusions may be drawn as per experimental outcomes for modulus of toughness analysis for feedstock filament.

- Based upon this experimentation, work shows the best parametric conditions for modulus of toughness has obtained at the parametric combination of 96Q+4, 50rpm, 200°C, 106 µm, and 20 kg load.
- The calculation of the delta value resulted in the ranking of process parameters. It has been observed as per delta value that barrel temperature has been ranked 1, followed by rotational speed ranked 2, forced loading ranked 3, the grain size of Hap ranked 4, and composition of materials ranked 5. This means, for extrusion, the barrel temperature should be considered as the most critical parameter.
- This result has observed that working (fabrication) temperature has maximum contributing factor

followed by rpm, load, and grain size of Hap and composition of materials is less contributing factor.

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References

[1] S. Murala and Q. M. Jonathan Wu, Spherical symmetric 3D local ternary patterns for natural, texture and biomedical image indexing and retrieval, Neurocomputing, 149 (2015) PC,1502–1514.

[2] S. Balaji et al., Characterization of keratin-collagen 3D scaffold for biomedical applications, Polym. Adv. Technol., 23(3)(2012) 500–507.

[3] F. Alam, V. R. Shukla, K. M. Varadarajan, and S. Kumar, Microarchitected 3D printed polylactic acid (PLA) nanocomposite scaffolds for biomedical applications, J. Mech. Behav. Biomed. Mater., 103(2020).

[4] N. Aggarwal, K. Kaur, A. Vasishth, and N. K. Verma, “Structural, optical and magnetic properties of Gadolinium-doped ZnO nanoparticles,” J. Mater. Sci. Mater. Electron., 27, (12)(2016) 13006–13011.

[5] P. Gairola, S. P. Gairola, V. Kumar, K. Singh, and S. K. Dhawan, Barium ferrite and graphite integrated with polyaniline as an effective shield against electromagnetic interference, Synth. Met., 221(2016) 326–331.

[6] M. Kaur and V. Wasson, ROI Based Medical Image Compression for Telemedicine Application, in Procedia Computer Science, 70(2015) 579–585.

[7] D. Rabha, A. Sarmah, and P. Nath, Design of a 3D printed smartphone microscopic system with enhanced imaging ability for biomedical applications, J. Microsc., 276(1) (2019) 13–20.

[8] R. C. Maurya, P. Bohre, S. Sahu, M. H. Martin, A. K. Sharma, and P. Vishwakarma, Oxoperoxomolybdenum(VI) complexes of catalytic and biomedical relevance: Synthesis, characterization, antibacterial activity, and 3D-molecular modeling of some oxoperoxomolybdenum(VI) chelates in mixed (O, O) coordination environment involving maltol and β-, Arab. J. Chem., 9(2016) S150–S160.

[9] R. Chaudhary, A. Jindal, G. S. Aujla, N. Kumar, A. K. Des, and N. Saxena, “LSCSH: Lattice-Based Secure Cryptosystem for Smart Healthcare in Smart Cities Environment,” IEEE Commun. Mag., 56(4)(2018) 24–32.

[10] S. Kumar, M. Kumar, and A. Handa, Combating hot corrosion of boiler tubes - A study, Eng. Fail. Anal., 94(2018) 379–395.

[11] Lalita, A. P. Singh, and R. K. Sharma, Synthesis and characterization of graft copolymers of chitosan with NIPAM and binary monomers for removal of Cr(VI), Cu(II) and Fe(II) metal ions from aqueous solutions, Int. J. Biol. Macromol., 99(2017) 409–426.

[12] M. V Varma, B. Kandasubramanian, and S. M. Ibrahim, 3D printed scaffolds for biomedical applications, Mater. Chem. Phys., 255(2020).

[13] A. Dhyani, N. Singh, V. Kumar, and A. Dhyani, Applications of 3 dimensional (3D) printing in the biomedical field, Int. J. Curr. Res. Rev., 12(19)(2020) 71–75.

[14] R. Kumar, R. Singh, M. Singh, and P. Kumar, On ZnO nanoparticle reinforced PVDF composite materials for 3D printing of biomedical sensors, J. Manuf. Process., 60(2020) 268–282.

[15] R. Hatibaruah, V. K. Nath, and D. Hazarika, 3D-local oriented zigzag ternary co-occurrence fused pattern for biomedical CT image retrieval, Biomed. Eng. Lett., 10(3)(2020) 345–357.

[16] Zainun Achmad Karmo Main, Al Emran Ismail ., Potential Applications of Fly-Ash and Sisal Hybrid Fibre Reinforced Plastic Composites International Journal of Engineering Trends and Technology 68.7(2020) 34-41.

[17] N. Mohite, L. Waghmare, A. Gonde, and S. Vipparthi, 3D local circular difference patterns for biomedical image retrieval, Int. J. Multimed. Inf. Retr., 8(2)(2019) 115–125.