Study of Effects on Mechanical Properties of PLA Filament which is blended with Recycled PLA Materials.

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Abstract: Fused deposition modeling is a rapidly growing additive manufacturing technology due to its ability to build functional parts having complex geometry. The mechanical properties of the build part is depends on several process parameters and build material of the printed specimen. The aim of this study is to characterize and optimize the parameters such as layer thickness and PLA build material which is mixed with recycled PLA material. Tensile and flexural or bending test are carried out to determine the mechanical response characteristics of the printed specimen. Taguchi method is used for number of experiments and Taguchi S/N ratio is used to identify the set of parameters which give good results for respective response characteristics, effectiveness of each parameters is investigated by using analysis of variance (ANOVA).

Key wards: Additive manufacturing, fused deposition modeling, recycled PLA, Taguchi method

1. Introduction
Fused deposition modelling (FDM) is a popular RP technology largely utilize in industries to build complex geometrical efficient parts in short time. The FDM uses plastic material in the form of continues wire filament to build 3D parts by melting the plastic filament and depositing on the surface. A plastic filament or metal wire in wounded form, is unwounded and supplies material to feeder where wire is loosened up from a loop and supplies material to an extruder which can control the stream. A worm-drive is provided to push the fibre into the extruder at a controlled rate. The extruder is heated up to a working temperature at which material starts melt. The resins are heated above their glass transition temperature and made them to pass through small orifice called heat break where resins get melted & then passes through Nozzle & deposited on printer bed to form the component.

Plastic manufacturers all over the world are burdened with environmental and waste management issues revolving around the efficient disposal of the post-industrial plastic waste, such as product rejects, plastic scrap, sprues, and runners. Obviously, plastic waste creates a significant problem to the manufacturers, as they need to comply with environmental regulations to prevent pollution. Thus, plastic recycling has drawn attention along with growing environmental concerns as well as the potential of economic benefits by establishing a waste reduction and recycling policy. The solution for these plastic wastes are by recycling and reusing for the downgrade applications.
In this work used PLA materials are recycled and converted into small pallets. This pallets are mixed homogeneously with virgin PLA pallets before extracting the build filaments. In total five PLA build filaments are manufactured using single screw extrusion technique. The difference in these filament is the percentage of recycled PLA material such as 10%, 20%, 30%, 40%, 50% in the build filament respectively.

The mechanical properties of the parts made by FDM primarily relies on upon depends on build parameters like layer thickness, build orientation and feed rate in which the part is build and the build material of the part[1][8][10][11]. Thus, it is essential to study the effects of recycled PLA particles in PLA build filament to attain desired quality characteristics in the parts developed by FDM process[2][3]. Design of experiments helps in investigation of impact of each these parameters on response characteristics of the FDM parts helps to adjust level of process variable leading to improvement in quality of parts [4]. Taguchi method is a widely accepted technique in engineering field to obtain and implement the efficient methods for design optimization. It has been extensively used for design and process optimization universal due to the advantages for design of experiments [5].

2. Experimental details:

2.1. Recycling of plastic

- Collection: Plastics are accessible in various structures, for example, plastic compartments, containers, bottles, plastic sacks, bundling plastic, because of their tendency and accessibility, the plastic gathering centers and some agents have wandered into plastic gathering business as a wellspring of income
- Sorting: The plastic reusing process begins with sorting of the distinctive plastic things by their sap substance and shading. This procedure is done to guarantee all defiles or contaminates are disposed of. At that point the recycling factory sorts the waste plastic by symbols at the base of the plastics
- Shredding: In the wake of sorting the plastics, the following stage is to cut the plastics into minor lumps or pieces. The plastic jugs and holders are then ground and cut into little pieces or drops. specially designed machine are utilized to isolate the heavier and lighter plastic pieces. The detachment procedure helps in guarantee the different plastics are not assembled or stirred up in the final product.
- Cleaning: Subsequent to separation process, the flakes or pieces are then washed with chemicals to remove whatever remains of the tainting. Once the cleaning step is finished, the perfect drops are gone through particular gear that further isolates the plastic resin type. The plastic pieces are then subjected to direct warming to dry.
- Melting: The dry flakes are liquefied down. The flakes can be softened down and framed into a desired shape or they are melted down and dealt with into granules. The softening procedure is completed under directed temperatures. There is particular machines intended to dissolving plastic without decimating them.
- Making of pellets: After the liquefying procedure, the plastic are then compacted into small pellets known as nurdles. In this the plastic pellets are prepared for reuse or be upgraded into new plastic items.
2.2. Filament extrusion process

Single screw plastics extrusion is a high-volume manufacturing process. It produces continuous profile by melting thermoplastic materials. The extrusion process starts with placing of plastic materials in the barrel through the hopper. Because of thermistor arranged on the surface of the barrel and mechanical energy generated by Turing screw the thermoplastic materials are homogenously mixed and melted. And this molten plastic is passed into die, this die shapes the molten plastic into a desired shape that hardens during cooling. The extrusion process produces items like pipe, plastic wires, plastic filming, thermoplastic coating.

2.3 Taguchi method
The Taguchi system is a generally recognized technique that suggestions a systematic and effective practice for design optimization. This is exclusively vital for rapid prototyping where production cost of prototypes is still elevated. The Taguchi orthogonal array is used to find number of experimental runs [5].

2.4 Experimentation Setup
In this study, two parameters such as layer thickness and percentage of recycled material in PLA filament are taken to study their effects on response characteristics such as tensile strength, flexural strength [7]. The layer thickness which is defined as the thickness of vertical deposited layer from the FDM nozzle as shown in Figure 2. The layer thickness process parameter is used to examine the stimulus of building thicker or thinner layers on the superiority of products. The orientation angle of part is defined as position of the part in which it is produced as shown in Figure 3.

Figure 1. Single screw extrusion process [6]
2.5 Experimental procedure
PLA build filaments is produced by adding different percentages of recycled PLA materials such as 10%, 20%, 30%, 40%, 50%. Parts to be manufactured were modelled using Catia V5 modelling software and transferred as STL file. The STL file is introduced to FDM ultimaker software. Parts were manufactured in Pramaan mini FDM printer having nozzle diameter of 0.4 mm. The parts are manufactured in FDM process as according to the ASTM standard. Tensile and flexural specimens were tested on universal testing machine of limit 20 ton. The dimensions of both tensile and flexural specimens are shown in Figure 4 and 5 respectively.

Table 1. Orthogonal Array

| #Runs | Parameters |
|-------|------------|
|       | A          | B          |
| 1     | 1          | 1          |
| 2     | 1          | 2          |
| 3     | 1          | 3          |
| 4     | 1          | 4          |
| 5     | 1          | 5          |
| 6     | 2          | 1          |
| 7     | 2          | 2          |
| 8     | 2          | 3          |
| 9     | 2          | 4          |
| 10    | 2          | 5          |
| 11    | 3          | 1          |
| 12    | 3          | 2          |
| 13    | 3          | 3          |
| 14    | 3          | 4          |
| 15    | 3          | 5          |
2.6 Design of Experiment (DOE)
It is an orderly method to acquire the connection between variables influencing a process and the output of that process. In this work set of parameters, for example, layer thickness and percentage of recycled PLA material in virgin PLA are considered and this input parameters influence the out parameters, for example, tensile and flexural strength appeared in Table 2. These output parameters are tested on universal testing machine having the 20 tons capacity.
Table 2. Input parameters that affect the output parameters

| #Runs | Layer thickness (mm) | Percentage of Recycled PLA materials (%) | Ultimate tensile strength (MPa) | Flexural strength (MPa) |
|-------|----------------------|------------------------------------------|-------------------------------|------------------------|
| 1     | 0.1                  | 10                                       | 37.829                        | 4.057                  |
| 2     | 0.1                  | 20                                       | 37.124                        | 3.976                  |
| 3     | 0.1                  | 30                                       | 35.702                        | 2.916                  |
| 4     | 0.1                  | 40                                       | 34.476                        | 2.454                  |
| 5     | 0.1                  | 50                                       | 33.417                        | 1.726                  |
| 6     | 0.2                  | 10                                       | 37.521                        | 2.960                  |
| 7     | 0.2                  | 20                                       | 37.046                        | 3.821                  |
| 8     | 0.2                  | 30                                       | 35.374                        | 3.624                  |
| 9     | 0.2                  | 40                                       | 33.411                        | 2.114                  |
| 10    | 0.2                  | 50                                       | 32.952                        | 1.189                  |
| 11    | 0.3                  | 10                                       | 37.486                        | 3.591                  |
| 12    | 0.3                  | 20                                       | 36.973                        | 3.383                  |
| 13    | 0.3                  | 30                                       | 35.046                        | 2.604                  |
| 14    | 0.3                  | 40                                       | 31.831                        | 1.991                  |
| 15    | 0.3                  | 50                                       | 30.270                        | 1.093                  |

Using DOE approach the conditions were generated for the experimental runs. For every run as shown in Table 2, the tests were carried and agreed for each run and each run result will contain response of tensile and flexural strength. The layer thickness is known to influence the final result in light of the fact that the smaller the layer thickness the more accurate the completed part will be when subjected to axial load. The materials in which the filament is manufactured is also influence the mechanical properties of the three printed part.

2.7 Cura Ultimaker
Cura Ultimaker of version 15.04 is open source software which refers that any individual can use the software [7]. It was used to print 3D parts using FDM process and Cura leads to change various process parameters before the parts are built and let’s to place the model where to be built within the build volume area, visualize the features of a part and also the manner in which the particular part is built.

Steps involved in Cura ultimaker

- Part loading
- Setting of process parameters
- Slicing of layers
- Conversion of layers into G-Codes
- Fabrication
3. Results and discussions:

Using traditional mechanical recycling processes, PLA can only be recycled to a lower material level, and so could be mostly used in less critical applications. Material states and mechanical properties of the recycled and reused parts are always the most important consideration when evaluating a recycling process for plastic. In this section, basic mechanical properties of 3D printed PLA specimens, impregnated with recycled PLA materials, were investigated and compared.

The main effect plot for ultimate tensile strength (UTS), and flexural strength are as shown in the Figure 6 and 7. The response variables are stated in the Table 2. The analysis of variance was used to found statistically significant parameters and proportion of contribution of these factors on ultimate tensile strength (UTS) and flexural strength. In Taguchi’s technique a loss function is used to work out the deviation between the experimental value and the desired value.

3.1 Tensile test

Tensile testing is the mechanical properties testing regularly used to acquire different information, for example, tensile strength, stress, yield, elasticity, strain, elongation and so on for various materials (metals, plastics, composites and so forth.). The test is utilized to decide the amount of force required to break a material.

![Figure 6. Tensile strength vs layer thickness](image-url)

Figure 6 shows the variation in tensile strength of build components, this components were produced with different combination of input parameters such as layer thickness and percentage of recycled PLA materials.
Figure 7. S/N ratio of tensile test specimen

Figure 7 shows the key impacts plot for Flexural Strength. In light of the valves of S/N ratio better valves for flexural strength is acquired by bigger valves of S/N ratio. On the premise of examination of S/N ratio the procedure parameters for succeeding bigger tensile strength are 0.1mm layer thickness and 10% recycled PLA materials in filament.

| Source                        | DF | Adj SS | Adj MS | F-Value | P-Value |
|-------------------------------|----|--------|--------|---------|---------|
| Layer thickness               | 1  | 4.819  | 1.916  | 8.61    | 0.012   |
| Percentage of recycled PLA    | 1  | 64.003 | 64.003 | 114.38  | 0.000   |
| Error                         | 12 | 6.715  | 0.5596 |         |         |
| Total                         | 14 | 75.537 |        |         |         |
3.2 Flexural strength
Flexure tests are used to decide the flexural modulus or flexural strength of a material. Flexural strength is characterized as the maximum stress at the furthest fiber on either the compression or tensile side of the specimen. Flexural modulus is ascertained from the slope of the stress versus strain deflection curve. These two esteem can be utilized to assess the specimen material's capacity to withstand flexure or bending forces.

![Figure 8. Flexural strength vs layer thickness](image)

Figure 8 shows the variation in tensile strength of build components, this components were produced with different combination of input parameters such as layer thickness and percentage of recycled PLA materials.
Figure 9 shows the key impacts plot for Flexural Strength. In light of the valves of S/N ratio better valves for flexural strength is acquired by bigger valves of S/N ratio. On the premise of examination of S/N ratio the procedure parameters for succeeding bigger flexural strength are 0.1mm layer thickness and 20% recycled PLA materials in filament.

| Source                  | DF  | Adj SS  | Adj MS | F-Value | P-Value |
|-------------------------|-----|---------|--------|---------|---------|
| Layer thickness         | 1   | 0.6086  | 0.6086 | 3.01    | 0.108   |
| Percentage of Recycled PLA | 1   | 10.5863 | 10.5863 | 52.42   | 0.00    |
| Error                   | 12  | 2.4233  | 0.2019 |         |         |
| Total                   | 14  | 13.5762 |        |         |         |

Figure 9. S/N ratio of flexural test specimen

TABLE 4. Analysis of Variance for ultimate flexural strength
4. Conclusion

Parameters were optimized for FDM process utilizing Taguchi's orthogonal array. Remarkable process parameters were determined utilizing ANOVA. The two process parameters varied were Layer thickness in three levels 0.1mm, 0.2mm, and 0.3mm and percentage of additives in PLA in five levels 10%, 20%, 30%, 40%, 50% and response characteristics like ultimate tensile strength, flexural strength, concluded by optimizing.

- The optimized process parameters for accomplishing larger tensile strength are 0.1mm layer thickness, 10% additives in PLA.

- The optimized process parameters for achieving larger flexural strength are 0.1mm layer thickness, 20% additives in PLA.

From the result it is conformed that some amount of strength left in plastic after they are used by recycling the plastic we can in downgrade applications.
Reference

[1]. J.M. Chacón, Miguel Ángel Caminero, Eustaquio García-Plaza, Pedro J. Nuñez López. “Additive manufacturing of PLA structures using fused deposition modelling: effect of process parameters on mechanical properties and their optimal selection” Volume 124, 15 June 2017, Pages 143–157

[2]. Rupinder Singh, Narinder Singh and IPS Ahuja “Recycling of Plastic Solid Waste for Additive Manufacturing Applications”, 6th International & 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016) College of Engineering, Pune, Maharashtra, INDIA December 16-18, 2016

[3]. J.D. Badia a,b, A. Ribes-Greus “Mechanical recycling of polylactide, upgrading trends and combination of valorization techniques” European Polymer Journal 84 (2016) 22–39.

[4]. C.A. Griffiths a, J. Howarth b, G. de-Almeida Rowbotham b, A. Reesa “Effect of build parameters on processing efficiency and material performance in fused deposition modelling” Procedia CIRP 49 (2016) 28 – 32

[5]. Samir Kumar panda, Saumyakant padhee, Anoop Kumar sood, S. S. mahapatra “Optimization of FDM process parameters using bacterial foraging technique” Intelligent Information Management, 2009, 1, 89-97.

[6]. Wayne C. Pollock, Stuart A. Grossman, Albert H. Owens Jr. Polymeric drug delivery systems and processes for producing such systems, Axxia Pharmaceuticals, Llc

[7]. Xiao Yong Tian a, Tengfei Liu a, Qingrui Wang a, Abliz Dilmurat a, b, Dichen Li a, Gerhard Ziegmann “Recycling and remanufacturing of 3D printed continuous carbon fiber reinforced PLA composites” Journal of Cleaner Production Volume 142, Part 4, 20 January 2017, Pages 1609–1618

[8]. M. Tymrak a, M. Kreiger b, J.M. Pearce, “Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions” Materials and Design 58 (2014) 242–246

[9]. Sheetal Ajit Chavan, Prof. M.A. Anwar, Prof. Shahab R. “Review of effect of process parameters on mechanical properties of 3d printed components” Vol No 6, Issue No. 05, May 2017.

[10]. Jayanth N, Senthil P and Vinodh S, “Experimental Investigation on Effect of Process Parameters on Tensile Strength of 3D Printed Poly Lactic Acid Specimens”, Proceedings of 6th International & 27th All India Manufacturing Technology, Design and Research Conference (AIMTDR-2016)

[11]. C K Basavaraj, M Vishwas, “Studies on Effect of Fused Deposition Modelling Process Parameters on Ultimate Tensile Strength and Dimensional Accuracy of Nylon”, IConAMMA IOP Conf. Series: Materials Science and Engineering, 149, (2016),01203,

[12]. Mahendrasinh M. Raj, Hemul V. Patel, Lata M. Raj and Naynika K. Patel, “Studies On Mechanical Properties Of Recycled Polypropylene Blended With Virgin Polypropylene”, International Journal of Science Inventions Today (IJSIT), 2(3), 2013, 194-203.
[13]. Ng Chin Fei, Nik Mizamzul Mehat, Shahrul Kamaruddin, Zulkifli Mohammad Ariff, A Degradation Study of Virgin and Recycled ABS Blends Subjected to Multiple Processing. International Journal of Research in Mechanical Engineering, Volume 1, Issue 1, July-September, 2013, pp.93-102.

[14]. Ng Chin Fei, Nik Mizamzul Mehat, Shahrul Kamaruddin, Zulkifli Mohammad Ariff, “A Degradation Study of Virgin and Recycled ABS Blends Subjected to Multiple Processing”, International Journal of Research in Mechanical Engineering, Volume 1, Issue 1, July-September, 2013, pp.93-102

[15]. K.G. Jaya Christiyan, U. Chandrasekhar and K. Venkateswarlu, “A study on the influence of process parameters on the Mechanical Properties of 3D printed ABS composite”, Materials Science and Engineering, 114 (2016), 1-8.