



IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY



VOLUME : 5 ISSUE : 7 Print / Issue Publication Date: 30-Jan-2021



ISSN : 2455-2143



DOI : 10.33564/IJEAST.2020.v05i07.050

Indexed In



WWW.IJEAST.COM

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SELECTION AND OPTIMIZATION OF MATERIAL FOR 3D PRINTING USING GREY RELATIONAL ANALYSIS

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Abstract— as we know that 3D printing is new emerging technology that growing fast and lots of research carried out on this topic. This paper show that there are different materials available for 3D printing, but we don't know which one is the better for printing if there is no requirement of special material. Every material shows different properties so it is difficult to select a single material for printing. For that purpose I used Grey Relational Analysis is a one of the optimization technique to select best material for printing.

Keywords— 3D Printing, AM, GRA

I. INTRODUCTION

1.1 Additive manufacturing

The term AM including many technologies subsets like Rapid Prototyping (RP), 3D Printing, Direct Digital Manufacturing, Layered manufacturing and additive fabrication [1].

AM builds products by adding one layer over another rather than by subtracting material from a larger piece of material like cutting out a helical gear from a AISI 4140 bar that is, “subtractive” manufacturing. This state small distinction adding rather than subtracting means everything. Assembly lines and supply chains can be reduced or eliminated for many products [2].

1.2 Classification of Additive Manufacturing

Liquid based technology:

- Stereo lithography (SLA)
- High viscosity Jetting
- Direct light processing technique
- The maple process

Powder based techniques:

- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Selective laser melting
- Selective inhibition sintering
- Electro photography layered manufacturing
- Selective masking sintering
- Fused metal deposition
- Electron beam melting

Solid based techniques:

- Sheet stalking technique
- Fused deposition modeling (FDM) [3].

1.3 3D Printing

The 3D printing is process which builds a three-dimensional object from a Computer Aided Design (CAD) model, by successively adding material layer by layer that's why it is called as additive manufacturing [4].

3D printing is also emerging as an energy efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilizing up to 90-95% of standard materials, and throughout the products operating life, through lighter and stronger design. It is used in variety of industries including jewelry, footwear, industrial design, engineering and construction, architecture, automotive, aerospace, dental and medical industries, education and consumer products [5].



Fig 1:- 3D printing process [5].

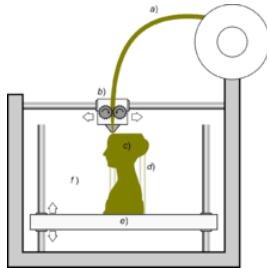
Stepwise procedure of 3D printing

We will refer to eight key steps in the process sequence:

1. Conceptualization and CAD
2. Conversion to STL
3. Transfer and manipulation of STL file on AM machine
4. Machine setup

5. Build
6. Part removal and cleanup
7. Post-processing of part
8. Application

1.4 Fused Deposition Modeling (FDM)



- a – Filament
 b – Nozzle
 c – Object
 d – Support
 e – Bed

Fig 2:- Fused Deposition Modeling (FDM)

Fused Deposition Modeling is one of the most widely used additive manufacturing processes for printing and fabricating plastic parts. FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. The process works by melting plastic filament that is deposited, through a heated extruder. Thickness of deposited layer onto a build platform according to the 3D data supplied to the printer [6].

1.5 3D Printing Materials

After different research carried out on 3D Printing materials following are some standard materials that use for 3D printing to print a better quality objects. We use GRA optimization technique for selection of a best material for 3D printing to improve the quality of print [7].

1. ABS

- ABS is chemically resistant to water.
- Low Cost
- Good impact and wear resistance
- Less oozing and stringing
- Good heat resistance [8].

2. PLA

- PLA is a biodegradable and low toxicity polyester
- PLA is considered an ecofriendly thermoplastic
- Low Cost
- Stiff and good strength
- Good dimensional accuracy

- Good shelf life [8].

3. NYLON

- Tough and partially flexible
- High impact resistance
- No unpleasant odor while printing
- Good abrasion resistance [7].

4. ASA

- ASA is a material that has similar properties to ABS, but has a greater resistance to UV rays.
- High impact and wear resistance
- High glass transition temperature [9].

5. PETG

- Water resistance
- Good impact resistance
- Glossy and smooth surface finish
- Adheres well to the bed with negligible warping
- Mostly odorless while printing
- Prone to wear [7].

6. CARBON FIBER

- Increased strength and stiffness
- Very good dimensional stability
- Light weight [10].

7. POLYCARBONATE

- High strength and durability
- Impact resistant
- High heat resistance
- Naturally transparent
- Bendable without breaking [7].

8. POLYPROPYLENE

- Good impact and fatigue resistance
- Semi-flexible
- Good heat resistance
- Lightweight
- Smooth surface finish [7].

9. WOOD FILAMENT

- Wood filaments combine a PLA base material with cork, wood dust, or other derivatives, giving the models a real wooden look and feel
- Wood-textured finish is aesthetically appealing
- Does not need any expensive wear resistant nozzles
- Aromatic and pleasant smelling [7].

10. PVA

- PVA, is a water-soluble polymer
- PVA is a colorless & odorless
- It's also low-toxicity [10].

Table -1 Material Properties

Properties	ABS	PLA	NYLON	ASA	PETG	CF	PC	PP	WOOD	PVA
Cost	Low	Low	High	High	High	High	High	High	High	High
Impact& Wear Resistance	High	-	High	High	-	-	High	High	-	-
Heat Resistance	High	Low	High	High	-	-	High	High	-	-
Abrasive Resistance	-	-	High	-	-	-	-	-	-	-
Chemical Resistance	-	-	-	-	High	-	-	-	-	-
Uv Resistance	-	-	-	High	-	-	-	-	-	-
Fatigue Resistance	-	-	High	-	High	-	High	High	-	High
Water Resistance	-	-	-	-	High	-	-	High	-	-
Oozing	Less	More	-	-	-	More	More	-	-	-
Wrapping	Heavy	-	Heavy	-	No	-	-	Heavy	-	-
Surface Finish	Smooth	-	-	-	Smooth	-	-	Smooth	-	-
Dimensional Accuracy	Low	High	-	-	-	High	-	-	-	-
Ordure	Pungent	-	No	-	No	-	-	-	Pleasant	-
Strength	-	High	-	-	-	High	-	Low	-	-
Brittle	-	Yes	-	-	-	-	-	-	-	-
Tough	-	-	Yes	-	-	-	-	-	-	-
Flexible	-	-	Yes	-	-	-	-	-	-	-
Heated Bed	Required	Not	-	-	-	Not	-	-	Not	-
Moist and Humidity Environment	-	-	Not Suitable	-	-	-	Not Suitable	-	-	-
Lightweight	-	-	-	-	-	Yes	-	-	-	-
Extrusion Temp	220-250°C	190-200°C	220-270°C	235-255°C	230-250°C	200-230°C	260-310°C	220-250°C	190-220°C	185-200°C
Flexible	-	-	Yes	-	-	-	-	Yes	-	Yes
Bed Temperature	95-100°C	45-60°C	70-90°C	90-110°C	75-90°C	45-60°C	80-120°C	85-100°C	45-60°C	45-60°C

1.6 Material Properties

Following are some properties of material shows in table no 1 that collected from a well known source [7]. Properties like Stiffness, Durability, and Printability of materials are given in a rank between 0-10. All the values of ultimate strength are taken as average between two values.

1. **Ultimate Strength:** - The maximum stress that material can withstand before breaking.

2. **Stiffness:** - Measure how difficult it is a bend to given material.
3. **Durability:** - Combination of Heat, Fatigue, Water, UV and Chemical resistance.
4. **Printability:** - How easy it is print with this materials best such factors warping, clogging etc.



Fig 3:- 3D Printing Filament

$$\Delta 0_i(k) = |x_0^*(k) - x_i^*(k)| \quad (3)$$

Step 3: Determination of Grey Relational Coefficient

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1. The grey relational coefficient $\gamma(x_0(k), x_i(k))$ can be expressed by Eq. 4.

$$\gamma(x_0(k), x_i(k)) = \frac{\Delta_{\min} + \zeta \Delta_{\max}}{\Delta 0_i(k) + \zeta \Delta_{\max}} \quad (4)$$

Where, $\Delta_{\min}$ is the smallest value of $\Delta 0_i(k) = \min_i \min_k |x_0^*(k) - x_i^*(k)|$ and $\Delta_{\max}$ is the largest value of $\Delta 0_i(k) = \max_i \max_k |x_0^*(k) - x_i^*(k)|$. $x_0^*(k)$ is the ideal normalized S/N ratio, $x_i^*(k)$ is the normalized comparability sequence, and ζ is the distinguishing coefficient. The value of ζ can be adjusted with the systematic actual need and defined in the range between 0 and 1; here it is taken as 0.5.

Step 4: Determination of Grey Relational Grade

$$\gamma(x_0, x_i) = \frac{1}{m} \sum_{i=1}^m \gamma(x_0(k), x_i(k)) \quad (5)$$

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. The grey relational grade is an average sum of the grey relational coefficients

Step 5: Determination of Optimal parameters

The grey relational grade calculated for each sequence is taken as a response for the further analysis. The larger-the-better quality characteristic was used for analyzing the GRG, since a larger value indicates the better performance of the process. The response table of Taguchi method was employed here to calculate the average grey relational grade for each factor level. In this, the grouping of the grey relational grades was done initially by the factor level for each column in the orthogonal array and then by averaging them

II. METHODOLOGY

Selection and optimization of various materials for FDM. Using Grey Relational Analysis

Raykar Sunil in their work addressed procedure for GRA. [12].

Step 1: Normalization of Data

The first step in grey relational analysis is normalization of data which is performed to prepare raw data for the analysis. Normalization of data in the range between zero and unity is also called as the grey relational generation. In this investigation "smaller-the-better" (1) criterion is used for normalization of Price and "Larger-the-better" (2) criterion is used for normalization of Ultimate Strength, Stiffness, Durability, Printability.

$$x_i^*(k) = \frac{\max_i x_i^{(o)}(k) - x_i^{(o)}(k)}{\max_i x_i^{(o)}(k) - \min_i x_i^{(o)}(k)} \quad (1)$$

$$x_i^*(k) = \frac{x_i^{(o)}(k) - \min_i x_i^{(o)}(k)}{\max_i x_i^{(o)}(k) - \min_i x_i^{(o)}(k)} \quad (2)$$

Step 2: Determination of deviation sequence

The deviation sequence $\Delta 0_i(k)$ is the absolute difference between the reference sequence $x_0^*(k)$ and the comparability sequence $x_i^*(k)$

$\Delta 0_i(k)$

$x_i^*(k)$ after normalization. It is determined using Eq.

3 as:

III. DESIGN OF EXPERIMENT

Table -2 Material Properties

MATERIAL	U/S	S	D	P	PR
ABS	40	5	8	1750	8
PLA	65	7.5	4	1750	9
NYLON	65	5	10	3150	8
ASA	55	5	10	2800	7
PETG	53	5	8	2800	9
CARBON FIBER	45	10	3	3850	8
POLYCARBONATE	72	6	10	3850	6
POLYPROPYLENE	32	4	9	6300	4
WOOD	46	8	3	2800	8
PVA	78	3	7	5250	5

Step 1: Normalization of Data

Table - 3 Normalization of data

Normalization of data				
U/S	S	D	P	PR
0.2830	0.2857	0.7143	1	0.8000
0.7547	0.6429	0.1429	1	1.0000
0.7547	0.2857	1.0000	0.6923	0.8000
0.5660	0.2857	1.0000	0.7692	0.6000
0.5283	0.2857	0.7143	0.7692	1.0000
0.3774	1.0000	0.0000	0.5384	0.8000
0.8868	0.4286	1.0000	0.5384	0.4000
0.1321	0.1429	0.8571	0	0.0000
0.3962	0.7143	0.0000	0.7692	0.8000
1.0000	0.000	0.5714	0.2307	0.2000

Table - 4 Determine Deviation Sequence

Determine Deviation Sequence				
U/S	S	D	P	PR
0.7170	0.7143	0.2857	0.0000	0.2000
0.2453	0.3571	0.8571	0.0000	0.0000
0.2453	0.7143	0.0000	0.3077	0.2000
0.4340	0.7143	0.0000	0.2308	0.4000
0.4717	0.7143	0.2857	0.2308	0.0000
0.6226	0.0000	1.0000	0.4615	0.2000
0.1132	0.5714	0.0000	0.4615	0.6000
0.8679	0.8571	0.1429	1.0000	1.0000
0.6038	0.2857	1.0000	0.2308	0.2000
0.0000	1.0000	0.4286	0.7692	0.8000

Step 3: Determination of Grey Relational Coefficient

Table – 5 Determination of Grey relational Coefficient

Determination of Grey relational Co-efficient				
U/S	S	D	P	PR
0.4109	0.4118	0.6364	1.0000	0.7143
0.6709	0.5833	0.3684	1.0000	1.0000
0.6709	0.4118	1.0000	0.6190	0.7143
0.5354	0.4118	1.0000	0.6840	0.5556
0.5146	0.4118	0.6364	0.6840	1.0000
0.4454	1.0000	0.3333	0.5200	0.7143
0.8154	0.4667	1.0000	0.5200	0.4545
0.3655	0.3684	0.7778	0.3330	0.3333
0.4530	0.6364	0.3333	0.7143	0.7143
1.0000	0.3333	0.5385	0.3846	0.3846

Step 4: Determination of Grey Relational Grade

Table – 6 Determination of Gray Relational Grade

Grade	Rank
0.6347	6
0.7245	1
0.6832	2
0.6374	5
0.6494	4
0.6026	7
0.6513	3
0.4357	10
0.5642	8
0.5301	9

Result and analysis

Table – 7 Rank

MATERIAL	U/S	S	D	P	PR	R
ABS	40	5	8	1750	8	6
PLA	65	7.5	4	1750	9	1
NYLON	65	5	10	3150	8	2
ASA	55	5	10	2800	7	5
PETG	53	5	8	2800	9	4
CARBON FIBER	45	10	3	3850	8	7
POLYCARBONATE	72	6	10	3850	6	3
POLYPROPYLENE	32	4	9	6300	4	10
WOOD	46	8	3	2800	8	8
PVA	78	3	7	5250	5	9

U/S – Ultimate Strength

D – Durability

PR – Printability

S – Stiffness

P – Price

R – Rank

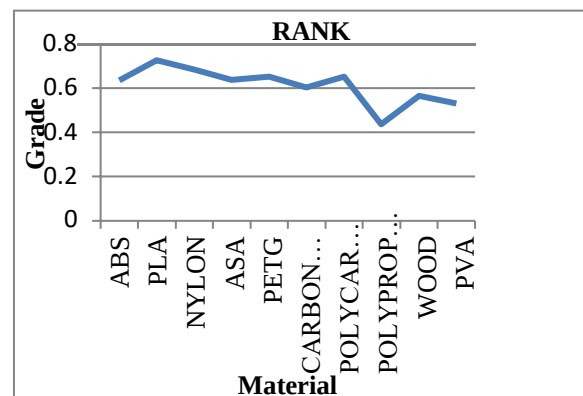


Fig 4:- Result



IV. RESULT AND DISCUSSION

In 3D Printing process minimum Price and maximum Ultimate strength, Stiffness, Durability and Printability are an indication of better performance. For data preprocessing in the gray relational analysis process, Price was taken as the “lower is better”, and Ultimate strength, Stiffness, Durability and Printability were taken as the “larger is better”,

In the first step we normalize data using Eq. 1 and Eq. 2 All the sequences after data preprocessing using Eq. 1 and Eq. 2 are listed in Table 3 and denoted as $x^*(k)$ and $x^*(k)$ for comparability sequences and reference sequence.

In second step we calculate Deviation sequence using Eq. 3 are listed in Table 4.

In 3rd step we calculate grey relational coefficient using Eq. 4 are listed in Table 5.

In 4th step we calculate grey relational grade using Eq.5 are listed in Table 6. The grey relational grade is an average sum of the grey relational coefficients.

According to the performed experimental design, it is clearly observed from Table 7 and Fig. 4 that PLA material has the highest gray relational grade. Therefore, PLA material has minimum Price and maximum Ultimate strength, Stiffness, Durability and Printability (i.e., the best multi performance characteristics) among the all materials.

V. CONCLUSION

The Grey Relational Analysis technique shows that PLA is best suitable material for 3D printing according to their different properties and price. If there is no requirement of any special properties.

RANK

1. PLA
2. NYLON
3. POLYCARBONATE
4. PETG
5. ASA
6. ABS
7. CARBON FIBER
8. WOOD FILAMENT
9. PVA
10. POLYPROPYLENE

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2455-2143