PARAMETRIC OPTIMIZATION OF RPT- FUSED DEPOSITION MODELING USING FUZZY LOGIC CONTROL ALGORITHM

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ABSTRACT

In this paper, the fuzzy logic algorithm for process parameters of fused deposition modeling is described. Rapid prototyping is moving towards rapid prototyping manufacturing (RPTM). Surface quality and dimensional accuracy are important with parts used for end purposes. The input process parameters taken for FDM 2000 are nozzle diameter, slice thickness and road width for the prediction of output process parameters such as surface finish, porosity and dimensional accuracy.

Fuzzy Logic helps in predicting the output parameters for the given machine specific input parameters. Once the output values are known, the effectiveness of the input parameters could be analyzed and changed suitably according to the purpose. These input and output variables play a crucial role in designing the fuzzy model for effective prediction. FLC designe offers the user the ability to quantify the trade-offs among conflicting goals while striving towards the best compromise solution

Keywords: Fuzzy logic, fused deposition modeling, surface finish, porosity, dimensional accuracy

1. INTRODUCTION

Fused deposition modeling (FDM) is one of the material deposition subfamilies of solid freeform fabrication (SFF) technologies [1]. According to the current situation there are certain predefined and preset parameters, which serve as an input to the FDM, rapid prototyping machine. With the increased application of RPT technologies in direct manufacturing, surface finish and dimensional accuracy are critical as they can affect the part accuracy, reduce the post processing costs and improve the functionality of the parts. Surface finish is a function of number of factors; amongst them are nozzle diameter, slice thickness, and road width. An optimal setting of these parameters would result in a FDM prototype with good surface quality [2,3,4].

Fuzzy Logic helps in the fabrication of quality RP components by predicting the output parameters that would be obtained for the given input parameter by efficient design of the fuzzy modeling. When certain crucial parameters like nozzle tip diameter, slice thickness, road width etc. are varied or even modified slightly, it might lead to large variations in the output parameters which is of paramount importance in the fabrication of the model. This might result in heavy loss and hence, in order to prevent such losses, fuzzy logic algorithm developed provides the more accurate results which are incorporated in the FDM machine.

This paper aims at optimizing and predicting the output parameters for the given input parameters of components that are to be fabricated by FDM rapid prototyping machine using Fuzzy Logic Algorithm.

2. EXPERIMENTAL PROCEDURE

Fused deposition Modeling is one of the most commonly used technique in Rapid Prototyping. FDM builds a 3D object layer by layer from a CAD design. A wax or thermoplastic (ABS) material supplied in the form of filament is heated inside the liquefier so it comes out in a molten liquid state. Successive layers fuse together and solidify to build up an accurate, three-dimensional model of the design.

Process variables that affect the FDM process are slice thickness, road width, nozzle diameter, part orientation, filament diameter etc. The quality and accuracy of the part depends upon these variables. So, there is a need to optimize these variables concurrently to get a high quality product.

The following input variables were considered and were used in the fabrication of the components

- Nozzle diameter in mm (T10-0.254 and T12-0.305)
- Slice thickness in mm (0.1778, 0.2, 0.254)
- Road width in mm (0.310, 0.411, 0.511, 0.610, 0.706)

The slice thickness has a direct impact on the surface finish of the part if the part has sloped surfaces in the direction of build. Use of smaller slice thickness reduces the staircase effect, but increases the time to fabricate. Road width and nozzle diameter have effect on surface as well as internal defects in the parts produced by FDM. To prevent void formation and other defects etc, the proper selection of road width and nozzle diameter is the must. In this work, for different combinations of slice thickness, road width and nozzle diameter, the surface roughness, dimensional accuracy, and porosity are determined.

One of the important aspects of Fuzzy Logic controller is fuzzifying inputs as membership functions [5,6]. To do Fuzzification process, experimental measures of various output parameters were made from the component fabricated using FDM machine with many different input parameters [7,8,9,10,11].

The following steps were carried out for the fabrication of the components. A suitable model was to be chosen for fabrication after considering the following factors. The component should be measurable in size. The components should have a flat surface, a concave surface and a convex surface. The component should be small, since the time taken for fabrication should be less.

The output parameters considered were the surface roughness of the component, the dimensional accuracy of the component and the porosity of the component. The following measurements were made and the values were tabulated in Table-1:

- Measurement of surface roughness parameter such as Ra for all the components using surtronic-3+.
- Measurement of the Depth and Width of all the components using a Digital vernier height gauge. (Measurements were taken at five different points and the average was taken for better accuracy).
- Deviation from Actual Width and Depth are calculated in terms of percentage (%)
- Measurement of weight of all the components using electronic weighing machine for the purpose of calculating the porosity.

Table 1.Tabulation of Experimental values

Slice thickness and Road width	Nozzle T10				Nozzle T12			
	R_a	Dev. from Depth	Red. In Width	Porosity	R_a	Dev. from Depth	Red. In Width	Porosity
mm	µm	%	%	%	µm	%	%	%
St=0.1778 & Rw=0.310	15.2	0.12	1.0546	12.19	16.3	1.685	2.638	13.38
St=0.1778 & Rw=0.411	7.2	1.425	0.678	10.04	4.6	1.563	1.892	8.72
St=0.1778 & Rw=0.511	8.9	1.514	0.198	3.3	8.9	-1.304	1.812	8.3
St=0.1778 & Rw=0.611	14.4	1.594	0.644	7.331	39	-0.98	1.532	9.55
St=0.1778 & Rw=0.706	14	2.281	0.411	4.204	21.6	-0.987	1.379	8.6
St=0.2000 & Rw=0.310	6.4	1.939	1.248	8.478	17.8	-1.255	4.372	13.3
St=0.2000 & Rw=0.411	20.6	2.11	1.3533	6.914	20.4	0.321	2.2353	7.61
St=0.2000 & Rw=0.511	9	2.099	1.182	1.806	14	1.921	1.929	7.08
St=0.2000 & Rw=0.611	37.2	4	0.805	1.598	35.4	1.972	0.533	4.13
St=0.2000 & Rw=0.706	11	3.239	-0.376	-1.529	13.2	2.728	0.169	4.27
St=0.2540 & Rw=0.311	16.9	-0.8	1.488	14.92	23.1	-1.459	2.2231	18.8
St=0.2540 & Rw=0.411	19	8.26	1.578	12.92	25	-1.989	2.035	13.44
St=0.2540 & Rw=0.511	11.7	0.457	1.7053	10.53	22.9	-2.7	2.024	14.6
St=0.2540 & Rw=0.611	14.8	1.85	1.44	9.17	12.2	-1.402	1.673	10.39
St=0.2540 & Rw=0.706	10	1.55	0.602	4.86	14.8	-1.2	1.0893	9.97

3. FUZZY LOGIC ALGORITHM

Fuzzy Logic Control (FLC) describes the algorithm for process control as a fuzzy relation between information on the condition of the process to be controlled and the control action. It is thus distinguished from the conventional control algorithms, since information (linguistic or fuzzy model) about the system rather than a mathematical model is what the designer needs. Fuzzy Logic is a very powerful method of reasoning when mathematical models are not available and input data are imprecise. Fuzzy Logic can be used to mathematically formulate imprecise concepts (like low, medium, and high) so they can be understood and processed by computers. The essence of fuzzy control algorithms is a conditional statement between a fuzzy input variable A and a fuzzy output variable B. A linguistic implication statement such as expresses this

IF A THEN B.

A fuzzy variable is expressed through a fuzzy set, which in turn is defined by a membership function $\mu(x)$. The fuzzy variable may be continuous or discrete. A continuous variable can be quantified and expressed as if it were discrete. In fuzzy systems, more than one rule may fire at the same time, but with varied strengths. This mixture of rules firing with varied strengths leads to a crisp control action through the process of defuzzification.

The fuzzy logic control system was designed by identifying the inputs and outputs using linguistic variables; assigning membership functions to the variables; building a rule base; and generating a crisp control action (Defuzzification).

The inputs to the fuzzy logic controller are Slice thickness and width. The output from the Fuzzy Logic Controller are surface roughness Ra, mass, depth and width of the part.

3.1 Membership Functions

The membership functions for the input variables St and Rw are shown in Fig-1. The membership function for the output variable Ra is shown in Fig- 2. The membership function plots are similar for mass depth and width. The various MF used in FL include triangular, trapezoidal and bell-shaped functions. Triangular MF is generally used because the parametric, functional description of this shape is the most economical, stored with minimal use of memory and manipulated efficiently, in terms of real-time requirements, by the inference engine. Each two adjacent MF have a cross point level of 0.5 and a cross-point ratio of 1, which provides significantly less overshoot, faster rise-time, and less undershoot. The rule base is given in Table-2.

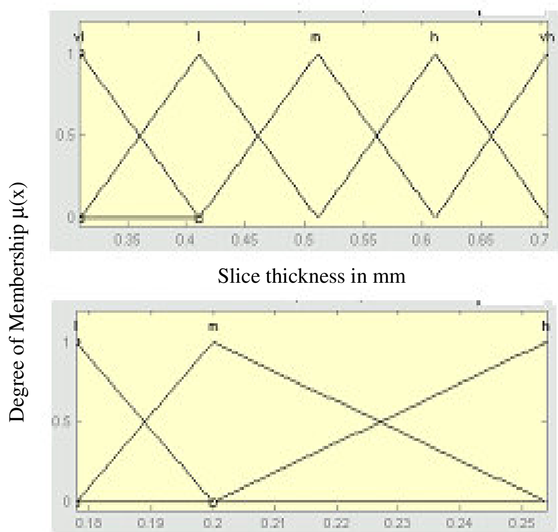

Fig-1 Membership function for input variables

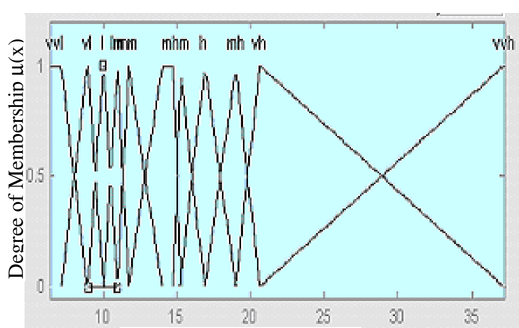

Fig-2 Membership function for out put variables

Table-2: Design of Interactions

Rw St	very low (VL)	low (L)	medium (M)	high(H)	very high (VH)
low (L)	high medium (HM)	very very low (VVL)	very low (VL)	medium (M)	medium (M)
medium (M)	very very low (VVL)	very high (VH)	very low (VL)	very very high (VVH)	low medium (LM)
high(H)	high(H)	moderate high(MH)	moderate medium (MM)	medium (M)	low (L)

The process of Defuzzification in fuzzy logic control systems is not standardized. There are several methods in use. The procedure used here was the centroid or center of area / gravity method.

4. RESULTS AND DISCUSSIONS

The Fuzzy logic values are given in Table-3. FIS information used for fuzzy logic control model is given in Table-4.

4.1 Surface Roughness

The surface roughness values are given Fig-3. It is observed that for all slice thickness, surface roughness (Ra) decreases for increase in road width. It can also be noticed that for increase in slice thickness, surface roughness increases Inferences. Each layer of deposition have rigid surface due to rounded top surface of the road. As road width increases the number of depositions decreases. Hence surface finish improves with increase in road width . When each layer of deposition have ridged surface of the previous layer, the surface roughness decreases. Hence surface finish improves with increase in slice thickness.

4.2 Porosity

The porosity values are illustrated in Fig-4. It is observed that for all slice thickness, as road width increases porosity decreases. Porosity is high for components fabricated with slice thickness 0.254 than components fabricated with slice thickness 0.1778 and 0.2 mm (for both nozzle). Porosity of components fabricated by T12 is greater than porosity of components fabricated by T10. This implies mass of components fabricated by T10 is greater than mass of components fabricated by T12. Maximum porosity occurs when St=0.254 and Rw=0.31 mm for both the nozzles T10 and T12.

4.2.*1 Inferences*

When road width is high, air entrapment into the filament is low. Hence porosity decreases with increase in road width. As nozzle diameter increases, air entrapment into the filament also increases resulting in reduction of mass. Hence porosity is high for the components fabricated by T12. Slice thickness does not have greater influence in porosity

4.3 Dimensional accuracy

From the Fig-5 it is observed that for all slice thickness, as road width increases depth also increases for nozzle T10. For all slice thickness, depth of components fabricated by T10 is greater than the depth of the components fabricated by T12.

Table-3: Fuzzy Logic values

Slice thickness and Road width	Nozzle T10				Nozzle T12			
	R_a	Dev. from Depth	Red. In Width	Porosity	R_a	Dev. from Depth	Red. In Width	Porosity
mm	µm	%	%	%	µm	%	%	%
St=0.1778 & Rw=0.310	15.6	0.3	1.01	12.8	16.3	1.3	2.65	13.5
St=0.1778 & Rw=0.411	7.22	1.1	0.807	10.7	5.41	1.3	1.91	8.6
St=0.1778 & Rw=0.511	8.72	1.5	0.08	3.4	8.57	-1.29	1.73	8.3
St=0.1778 & Rw=0.611	13.8	1.6	0.573	6.9	5.41	-0.62	1.23	9.3
St=0.1778 & Rw=0.706	13.8	2.5	0.407	3.4	21.7	-0.62	1.23	8.6
St=0.2000 & Rw=0.310	7.22	1.9	1.307	8.6	18.2	-1.29	3.96	13.5
St=0.2000 & Rw=0.411	25.6	2.1	1.307	6.9	19.9	0.3	2.3	9.3
St=0.2000 & Rw=0.511	8.72	2.1	1.16	1.3	13.7	2.1	1.91	6.9
St=0.2000 & Rw=0.611	31.8	3.8	0.807	1.3	11.7	2.1	0.613	5.1
St=0.2000 & Rw=0.706	10.9	3.2	-0.2	-0.4	15	2.5	0.613	5.1
St=0.2540 & Rw=0.311	17	-0.51	1.467	14.2	23.2	-1.8	2.3	17.6
St=0.2540 & Rw=0.411	18.8	1.9	1.587	12.8	24.4	-1.8	2.06	13.5
St=0.2540 & Rw=0.511	12.2	0.3	1.67	10.7	23.2	-2.3	3.37	15.6
St=0.2540 & Rw=0.611	13.8	1.6	1.467	8.6	11.7	-1.15	1.73	12.1
St=0.2540 & Rw=0.706	9.9	1.6	0.573	5.5	15	-1.15	20.6	10.7

Table-4: FIS information used for fuzzy logic control model

Sl. No.	Details	Type/Value
1	Type of inference	Mamdani inference
2	Number of inputs	2
3	Number of outputs	4
4	Number of input membership functions	[3 5]
5	Number of output membership function	9-11
6	Number of output rules	15

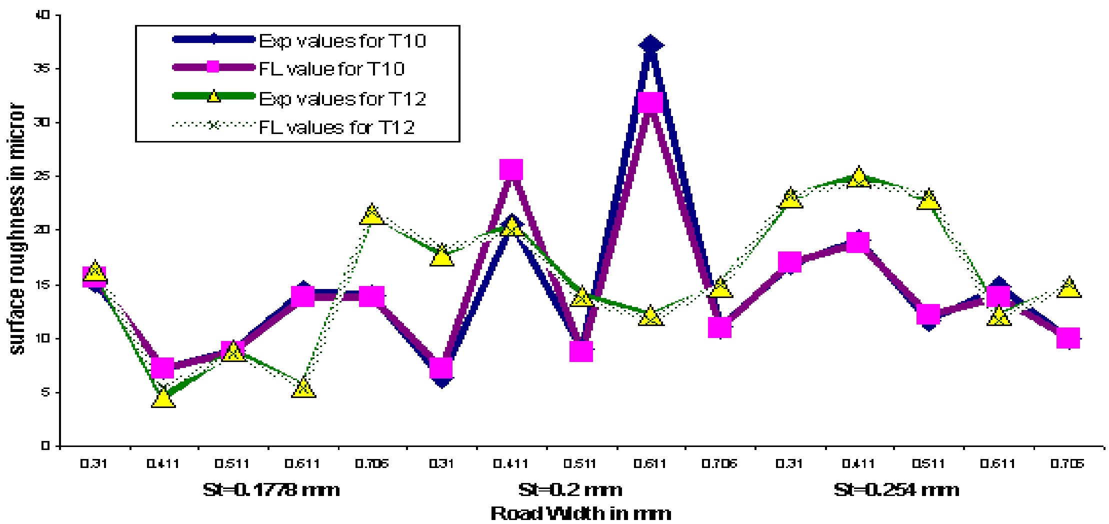

Fig-4: Surface roughness values

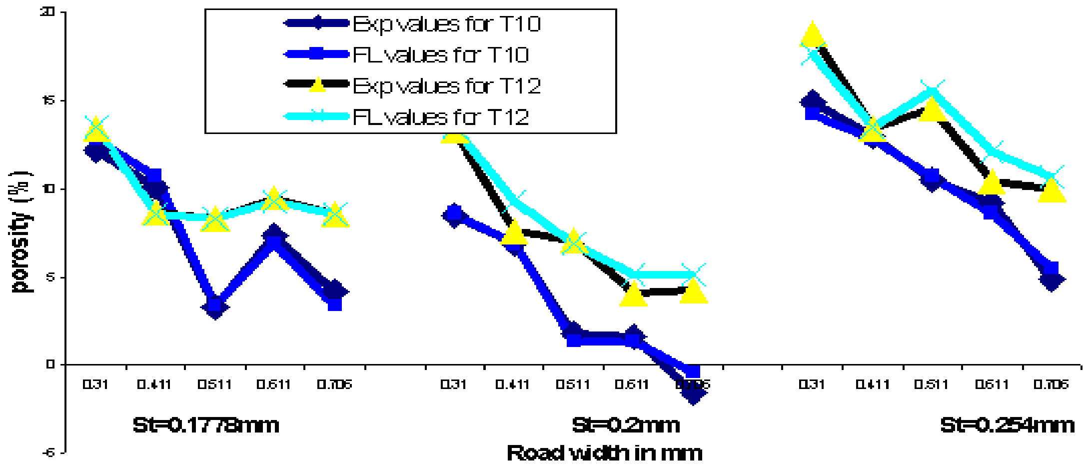

Fig-4 Porosity Values

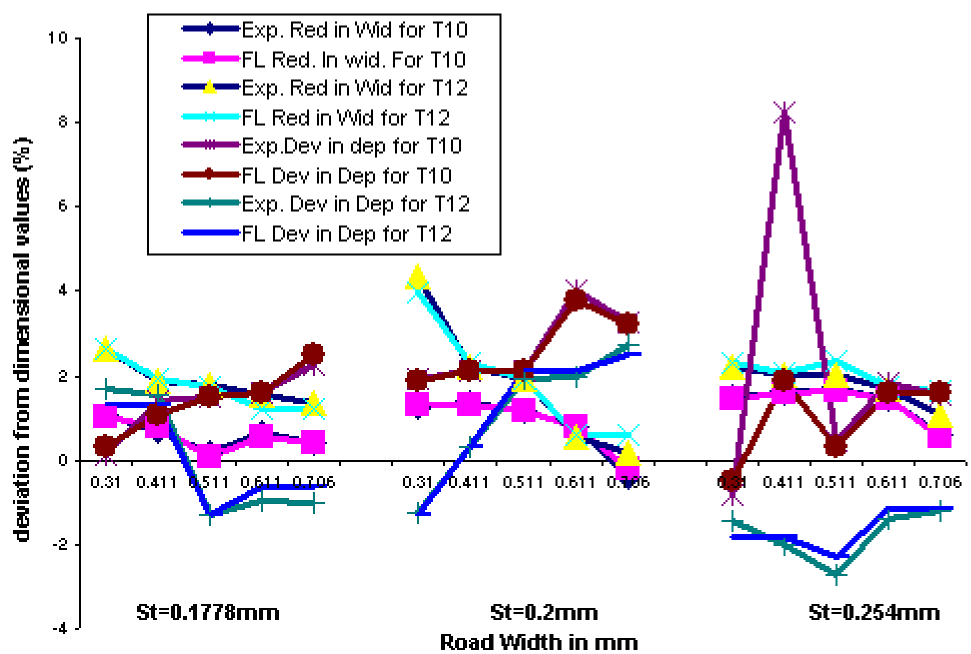

Fig-5 Dimensional accuracy values

For all slice thickness, as road width increases width also increase for both nozzles T10 and T12. For all slice thickness, depth of components fabricated by T10 is greater than the depth of the components fabricated by T12. Width of components fabricated by nozzle T10 and T12 are less than the actual width of the component. Depth of components fabricated by nozzle T10 and T12 are greater than the actual depth of the component

4.3.*1 Inferences*

Side flow is low for smaller road width and hence width of components are less for smaller road widths where as it increases for larger road width.

5. CONCLUSIONS

FDM offers the potential of producing parts directly from a CAD model using layer-by-layer deposition of extruded material. In using this technology, the designer was often confronted with a host of conflicting options including achieving desired accuracy, optimizing surface finish and porosity and fulfilling functionality requirements. Presents a solution for resolving these problems by the use of Fuzzy Logic Control Model.

After suitable literature survey, the various input variables and the output variables were found out. A suitable model was selected and the components were fabricated using FDM machine. The required parameters were then measured. The fuzzy logic control model was designed incorporating all the experimental data separately for each nozzle diameter and output parameters. The input and output values were provided to the Fuzzy Logic Inference Editor to define the fuzzy set. Then fuzzified the input parameters to generate the output, which was to be defuzzified. The output patterns predicted from the Fuzzy Logic Control

Model were accurate with maximum deviation of 5-10% from the experimental value, which is negligible.

Thus FLC designed offers the user the ability to quantify the trade-offs among conflicting goals while striving towards the best compromise solution.

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