AN EXPERIMENTAL APPROACH FOR THE OPERATIONAL PARAMETERS ON THE FILAMENT WIDTH IN DEPOSITION MODELING IN RAPID PROTOTYPING PROCESS AT ROOM TEMPERATURE

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***Abstract**: In rapid prototyping (RP) the melting of material is, generally, executed by means of laser or electric resistance heating. This type of transformation during the prototyping process also results on high cost of prototype and equipment. Another possibility that is presented, however, is the use of alternative material for a process of transformation which doesn't make use of laser nor electric resistance heating. In this article, experiments are presented in which a process of deposition named Deposition Modeling at Room Temperature (DMRT) is used. Such process makes use of alternative material at room temperature and the experiments deal with speed of deposition and relative speed (difference between the speed the of displacement of the surface of the deposited filament and speed of deposition) to determine, statistically, their level of contribution on the width of the deposited filament. By that means, it is attempted to assist on the substantiation of the DMRT process by achieving knowledge about the characteristics of process parameters in RP generation.*
***Key words**: rapid prototyping, deposition at room temperature, deposition.*

1. INTRODUCTION

The operating parameters involved in rapid prototyping processes (RP) differ from the conventional machining processes, because the principle of prototype generation, in rapid prototyping machines, is made layer by layer, using thermo-stable resins in laser processes (*stereolithograpy) or post-metallic and non-metallic* (*laser sinter*), or thermoplastic (*Fused Deposition Modeling*) obtained through electric resistance fusion.

In *stereolithograpy* and *laser sinter* processes, there are the operating parameters of: focus adjustment and diameter, depth adjustment, etc (Schubert, 1999), during the use as an energy source for the fusion of the metallic or thermoplastic powder, or solidification of the liquid resin (Hinse, 1998; Leibinger, 2003). However, in *Deposition Modeling* there are as parameters time duration of heating, material flux, pressure, speed of displacement on axis “X”, “Y” and “X” and duration of pauses, deposition flux, among others.

The knowledge about the operational parameters is of major importance in order to produce the conditions for transforming the material from solid to liquid or vice-versa. In material deposition specifically, there is a continuous flux, and subsequently the operating parameters balance is important to generate prototypes which have shapes, dimensions and tolerances that may be generated by the process without letting excess or lack of material occur (Anitha, Arunachalam, Radhakrishnan, 2001) (Künstner, 1999).

By using an alternative process of deposition at room temperature (Deposition Modeling at Room Temperature – DMRT) which uses an alternative material (composite made of carbohydrate), there are the following operating parameters: material flux, deposition and relative speed .In this article the level of contribution of the speed of deposition and the relative on the deposited filament width is determined statistically, using data obtained from experiments.

2. MATERIALS AND METHODS

The knowledge about the operating parameters in deposition rapid prototyping processes is important in the generation of a prototype through layer by layer deposition of filaments. The filament dimensions influence on the generated prototype technical specification (geometric shape, tolerances, and surface roughness, among others), so that a statistic study about DMRT (using a carbohydrate-based composite) is also necessary.

In deposition modeling at room temperature (DMRT) the deposition of the material (carbohydrate-based composite) is in filament format, and during the deposition, the XY table is displaced. The speed of deposition and relative speed are studied in order to verify the level of contribution of these parameters, by ANOVA (analysis of variance), measuring the filament width, after injecting carbohydrate-based composite on an acrylic plate on the table surface.

2.1 Materials

The carbohydrate-based composite is initially a homogeneous paste, which facilitates its flow while being injected. This consistence doesn’t require heating, not only at the place where the filament is going to be injected, but also for the layer by layer material deposition operation, because in the carbohydrate composite there are elements that, besides facilitating the flowing and diminishing resistance on the cylinder’s internal walls, also make possible more flexibility and malleability during the injection process.

For this experiment to be carried out, a mechanical device, Fig. 1, for injecting materials was used, which was able to study the process of material deposition in filament format. The mechanical device was designed to make possible the adjustment and measurement of the operating parameters during the process of deposition of material at room temperature. The DC motor transmits movement to the gearbox and this transmits movement to the screw, in direction to Z, on low rotation rate, and, as a result, it controls the flux of the material through the injection nozzle.

There is a gearbox connected to the screw, which transmits movement to a piston placed inside the cylinder, which displaces the material that is inside the cylinder. That material is injected, under pressure, through the injection nozzle, in order to deposit filaments of various dimensions on the table (item 3), which is displaced horizontally.

The device was installed on a Z axis of a CNC[1] didactic milling machine (vertical displacement), as shown in Figure 02 (brand: EMCO, model: F1– CNC), making possible to emulate the movements of a RP machine.

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[1] The software shown in F1 – CNC, aims at didactic training. The available resources are intended to programming of basic pieces, with programs limited to 250 lines, which makes possible inserting the program for generating pieces layer by layer and determining speed of displacement, among others.

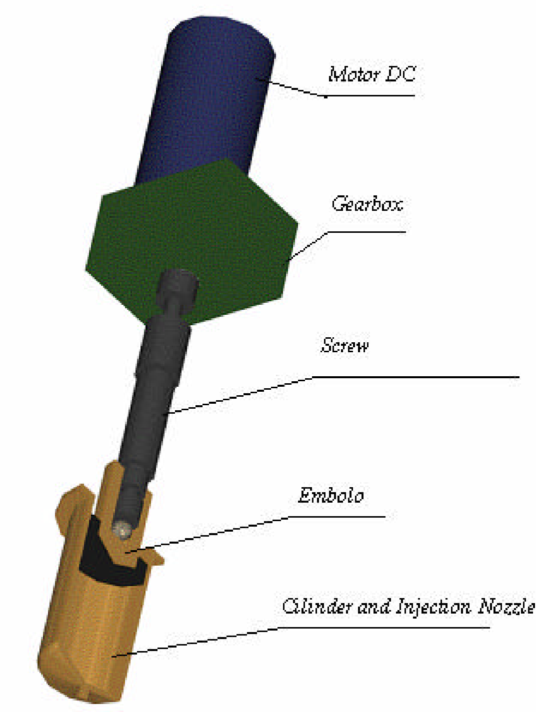
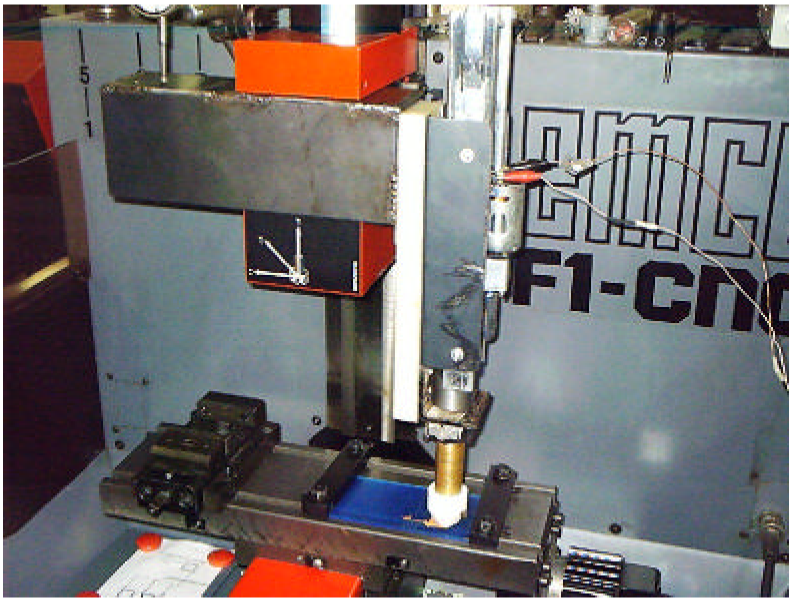


Figure 1: Constituting elements of the “injecting device” system



Figur 2: Device built on a CNC milling machine

2.2 – Methods

In figure 3 there is a sequence of steps done in the adopted method in order to empirically determine the flux and operating parameters that will be used in filament deposition in DMRT process, as described below:

I. The injector device is started by the continuous progress of the embolus and injects filaments continuously through a nozzle. An interval of time of two minutes was adopted in order to the volumes of injected material to be obtained. These volumes are going to be used to obtain the numerical values of these volumes from stage *II*;

II. Each sample is going to be manually compacted after the deposition and will be placed in a graduated bulb (total volume of 2ml – precision of 2ml) for the volume of displaced liquid to be measured;

III. For the verification of displaced volume (*Y*) the level of liquid (*X*) was determined in the bulb at the last stage. The difference between levels will provide the volume of material deposited for the period of 2 minutes;

IV. From each sample, the volume of material was obtained by repeating stages from I to III;

V. The process of obtainance of samples was carried out for 20 samples that resulted in values of volume (*ml*) and the average value of displaced volume was calculated;

VI. The average value of displaced volume was calculated and the nozzle's diameter used was 0,71 mm. The values of the flux general formula ($Q=V/t$) were applied and the average speed of deposition (Sd) was calculated for 3 different fluxes, obtaining approximately 325, 337, 371 and 388 mm/min for each. Still in this stage , a range of excess and lack (lengthening) of material for the relative speed (Rs) accordingly to the speed of deposition, as follows:

- $Rs_{-25} = Sd$: corresponds to the limit range of excess of material: It was adopted up to -25 mm/min over average speed of deposition as the maximum limit to observe the influence of accumulation of material on surface roughness and geometrical shape of the prototype;
- $Rs_0 = Sd$: corresponds to the ideal value, for the described conditions for material deposition without letting occur excess or lack of material: Speed of displacement of the surface of deposition is the same as speed of deposition and the influence on surface roughness and geometrical shape pf the prototype is going to be monitored;
- $Rs_{+25} = Sd$: corresponds to the limit range of lack (lengthening) of material: up to + 7,5% above speed of deposition was adopted as maximum limit for observing the influence of lack (lengthening) on the prototype's roughness and geometrical shape;

VII. The programming of the trajectory's coordinates, from the nozzle from which the material comes from, was made line by line in G[2] code in order to deposit the filaments on the surface of the milling table for the filament's width to be verified, according to the conditions described above.

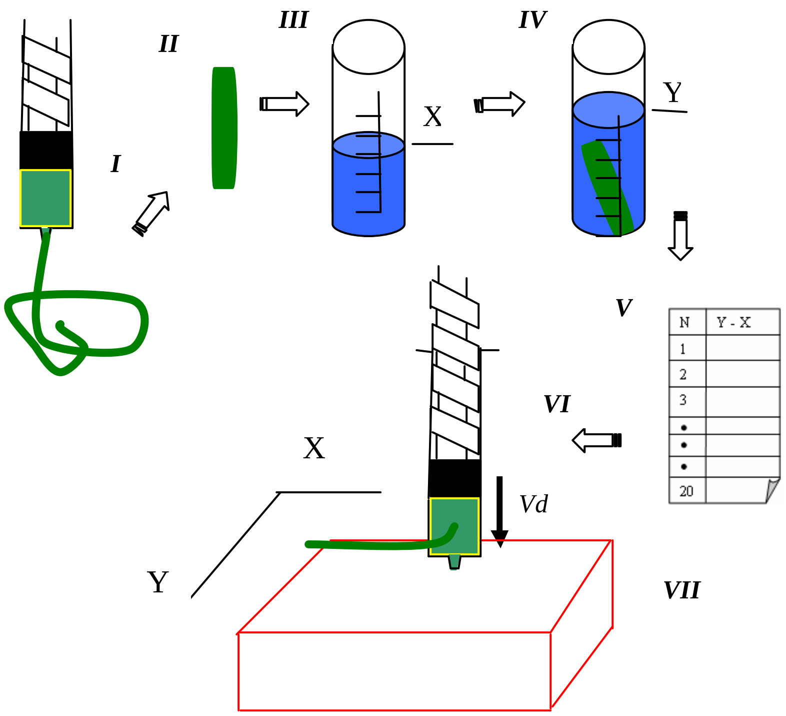


Figure 3: Sequence of steps done to obtain the operating parameters and their use in prototype generation in DMRT

[2] ISO (International Organization for Standardization) adopted a form of programming the displacent axis of the machine in G code.

The statistic treatment of the filament width will be done using ANOVA, a well known technique for interpretation of experimental data. In a general way, ANOVA's purpose is to test different significances among variances and to verify if there is any significant difference between averages, or if the parameters (the speed of deposition and relative speed) for deposition in DMRT process) have any influence on any dependent variable (filament's width). The implementation of the ANOVA procedure was based on (Drumond, Werkema, Aguiar, 1996) and (Piegel, Schiller, Srinivasan, 2004).

3. EXPERIMENTS

In table – 01 there are the values of speed of deposition (4 levels), speeds of displacement of the surface of the CNC table (mm/min) are used for the calculation of the relative speed (3 levels) and also in the programming of CNC machine. By the employ of these parameters, the values for the sample filaments width, to be treated statistically, were obtained by analysis of variation (ANOVA) to obtain which factors affect the filament's width at a larger scale while the material is being deposited.

Table 1: Values of operating parameters

Speeds of deposition (mm/min)				Speeds of displacement of the table (mm/min)											
325	**337**	**371**	**388**	**300**	**325**	**350**	**312**	**337**	**362**	**346**	**371**	**396**	**363**	**388**	**413**
				Relative speeds (mm/min)											
				-25	0	+25	-25	0	+25	-25	0	+25	-25	0	+25

48 sample filaments (table - 02) were deposited and measured by using a universal optical microscope and the values were statistically treated by variation analysis. This analysis permits the obtaining of the level of contribution of a determined factor (or factors) that affect a product's or process's quality and, specifically in this study, the geometrical shape of the deposited filament. It is noticeable that the height of deposition was kept constant for all the combinations between the speeds mentioned above.

Table 2: Values of the sample filaments width

		Relative speeds (mm/min)		
		+25	**0**	**-25**
Speed of deposition (mm/min)	325	0,67	0,73	0,71
		0,65	0,71	0,7
		0,66	0,73	0,72
		0,64	0,71	0,74
	337	0,64	0,69	0,72
		0,64	0,67	0,71
		0,66	0,66	0,7
		0,61	0,64	0,66
	371	0,67	0,77	0,78
		0,65	0,72	0,75
		0,63	0,66	0,72
		0,63	0,7	0,75
	388	0,68	0,7	0,76
		0,69	0,7	0,75
		0,7	0,7	0,77
		0,66	0,7	0,75

4. RESULTS ANALYSIS

Table 3 was built as an electronic application (Excel) and makes it possible to verify the results when it comes to contribution and significance of the factors (speed of deposition and relative speed). It is possible to notice that relative speed has a very significant contribution, followed by speed of deposition in a lower degree. The contribution of the interaction between these two is not expressive. Such results lead to operating parameters that influence on the geometrical dimensions of the filament width.

Tabela 3: Analysis of Variation (ANOVA)

Variação		Degree freedom	Square average	F	DF num	DF den	F 5%	Contribution (%)
Variation of speeds of deposition	vd	3	0,0048	10,33	3	36	2,88	**17,1**
Variation of relative speeds	vr	2	0,0231	49,66	2	36	3,27	**54,9**
Subtotal variation	sv	11						
Variation due to interaction	vi	6	0,0011	2,44	6	36	2,38	**8,1**
Residual variation	rv	36	0,0005					**19,9**
Total variation	v	47						

5. CONCLUSIONS

Having the results of the experiments as a base, it is observed, in statistical treatment, that the contribution of variation due to the interaction between speed of deposition and relative speed are not expressive (2,38%) compared to the contribution of variation of relative speeds (54,9%) and contribution of the speeds of deposition (17,1%) on the geometrical dimension of the filament width. The contribution of residual variation (19,9%) is also expressive and suggests that the process is suffers alterations from factors that are still unknown and need to be identified, because they affect the filament width.

The results denote the importance of the values of speeds for the accumulation of material not to occur (wider filament width) or lack of material (narrower filament width). That makes possible the determination of the operating parameters of DMRT (Deposition Modeling at room temperature) using a carbohydrate-based composite.

Such results reveal interesting characteristics in the continuous deposition process of the carbohydrate-based composite at room temperature. They also suggest the development of a method that eliminates or diminishes variation on the filament's width in relation to the expected width or makes it possible to adjust the process parameters (injection nozzle format, diameter, inclination, etc.) for having the wanted width. In which the filament width itself may be a parameter to be chosen in the process, because a narrower width means better resolution on prototype construction, and wider width means less time of construction.

Another possibility that needs to be studied is adjusting the distance for deposition, which may facilitate adherence pressure between filaments or even between layers, which must be done together with study of swelling coefficient, because the material may have dimensional variation after the injection. This study is important for evaluating the relation between diameter, flowing and pressure, and others.

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7. REFERENCES

ANITHA, R.; ARUNACHALAM, S.; RADHAKRISHNAN, P.. Critical parameters influencing the quality of prototypes in fused deposition modeling. Journal of Materials Processing Technology, v. 118, issues 1-3, pp. 385-88, december 2001.

DRUMOND, F. M.; WERKEMA, M.C.C.; AGUIAR, S.. Análise de variância: Comparação de variais situações, 1ª Ed., V.. 6, Belo Horizonte, Fundação Christiano Ottoni, Brazil, 1996, 276 p.

HINSE, Stern A.Laserheißdrahtbeschichten. 1998. Tese (Doutorado) – Fakultät für Bergbau, Hüttenwesen und Maschinenwesen, Technischen Universität Clausthal, Clausthal, Germany. 1998.

KÜNSTNER, Matthias. Beitrag zur Optimierung des Multiphase Jet Solidification (MJS) – Verfahrens zur Freiformenden Herstellung funktionaler Prototypen. 1999. Tese (Doutorado) – Universität Bremen, Bremen, Germany.

LEIBINGER, Berthold. Der Laser in Deutschland – ein Erfolgsmodell zwischen Wissenschaft und Industrie. Stuttgarter Lasertage ´03, p 6-7. 2003. Germany.

SCHUBART, Doris. Prozeßmodellierung und Technologieentwicklung beim Abtragen mit CO_2 - Laserstrahlung. 1999. Dr. Ingenieuer Thesis – Bericht aus dem Lehrstuhl für Fertigungstechnologie (LFT), Technischen Fakultät der Friedrich Alexander Universität Erlangen- Nürnberg, Germany.

PIEGEL, M.R.; SCHILLER, J.; SRINIVASAN, R.A. Probabilidade e Estatística, 2a Edição, Porto Alegre, Ed. Bookman, Coleção Schaum, 2004, 398p.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.

MODELAGEM EXPERIMENTAL DOS PARAMETROS OPERACIONAIS DA LARGURA DO FILHAMENTO DEPOSITADO EM MODELAGEM DO PROCESSO DE PROTOTIPAGEM A TEMPERATURA AMBIENTE

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***Abstract**: Na prototipagem rápida (PR) a fusão do material é conseguida geralmente por meio de aquecimento resistivo ou por raios LASER. Este tipo de transformação durante o processo de prototipagem resulta em custo elevado do protótipo e do equipamento. Uma outra possibilidade que é apresentada, contudo, é o uso de material alternativo para um processo de transformação que não necessite aquecimento resistivo ou por raios LASER. Neste trabalho, alguns experimentos são apresentados nos quais se emprega um processo de prototipagem por deposição a temperatura ambiente (PDTA). Este processo emprega materiais alternativos a temperatura ambiente e os experimentos são modelados em função da velocidade de deposição e velocidade relativa (diferença entre a velocidade de deslocamento da superfície do filamento depositado e a velocidade de deposição) para determinar, estatisticamente, seu nível de contribuição para com a largura do filamento depositado. Através deste modelo, se auxiliar uma melhor compreensão do processo de PDTA através dos conhecimentos adquiridos sobre os parâmetros característicos na geração do protótipo.*
***Palavras-chave**: prototipagem rápida, deposição a temperatura ambiente, deposição .*