Semana de Engenharia 2010
Guimarães, 11 a 15 de Outubro

FREE FORM EXTRUSION: EXTRUSION OF 3D COMPONENTS USING COMPLEX POLYMERIC SYSTEMS

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KEYWORDS

Free Form Extrusion, Heat Transfer, Modelling, Adhesion.

ABSTRACT

The performance of parts produced by Free Form Extrusion (FFE) may be limited by poor mechanical properties, due to poor bonding between the individual extruded filaments. In this work, an analytical solution is proposed for the transient heat transfer during filament deposition, taking into account contacts between filaments. The developed code using Matlab® allows to study the influence of the main process variables during filament deposition and may assist the process optimization.

INTRODUCTION

Free form extrusion (FFE) is a 3D fabrication process that evolved from rapid prototyping technology. It involves the deposition of an extruded filament following a specific trajectory in the X–Y plane (according to the part geometry), the process being repeated for the required number of layers.

Effective bonding between adjacent filaments is mandatory for making parts with adequate mechanical properties. Thus, upon deposition, each filament must be sufficiently hot, but excessive temperatures may promote too much deformation due to gravity. Therefore, it is important to know the evolution of the temperature of the filaments with time and how this is affected by major process variables.

Some work has been done previously on this topic. Rodriguez [Rodriguez, 1999] studied cooling of five elliptical filaments deposited on top of each other via finite element methods (FEM) and later found a 2D analytical solution for rectangular cross-sections [Thomas et al 2000]. Yardimci et al. [Yardimci et al, 1996] developed a more general 2D heat transfer analysis model also using FEM. Li and co-workers [Li et al 2003; Sun et al 2004] developed an analytical 1D transient heat transfer analysis of a single filament, using the Lumped Capacity method. Though good agreement with experimental results was reported, the model cannot be used for a sequence of filaments, as

The present work expands the above efforts, by aiming at developing a transient heat transfer analysis of filament deposition taking into account the effect of the main FFE variables, particularly that of the physical contact between any filament and its neighbours or supporting table.

HEAT TRANSFER ANALYSIS

Regardless of the shape and deposition sequence, during the creation of a part by FFE each of its individual filaments is subjected to the same heat transfer mechanism, but the boundary conditions vary. One may have to consider heat flux with the support, with the surrounding environment, with colder filaments deposited before and with younger hotter filaments deposited afterwards (Figure 1).

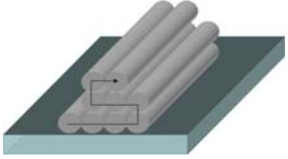
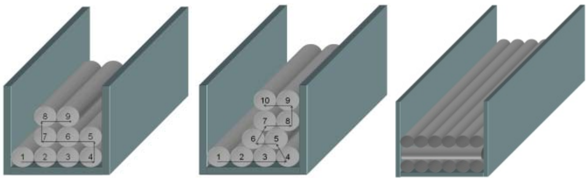


Figure 1 – Possible sequence of filaments deposition.

Consider that N is the total number of deposited filaments and $T_r(x,t)$ is the temperature on the point x of the r-th filament ($r \in \{1,\ldots,N\}$), at the instant t. The energy balance for an element dx of the r-th filament with the relevant boundary conditions was done, yielding a differential equation, which was solved using the polynomial characteristic method. In order to evaluate the influence of the main processing variables, a computer code, based in the analytical solution, was developed using the Matlab® software.

The temperature evolution along deposition time for each one filament can be computed for any of these three possible deposition sequences (unidirectional and aligned filaments, unidirectional and skewed filaments and perpendicular filaments) as illustrated in Figure 2.



a) b) c)

Figure 2 – Deposition sequences. a) Unidirectional and aligned filaments; b) Unidirectional and skewed filaments; c) Perpendicular filaments.

Knowing the temperature evolution along deposition time for each one filament is possible to obtain relevant information about the final part quality, such as, the adhesion between the filaments after construction of the part by FFE. In fact, the inexistence of areas with poor adhesion indicates that the mechanical resistance of the part is maximized.

In order to achieve this, a specific computer code was developed using the Matlab® software (Figure 3).

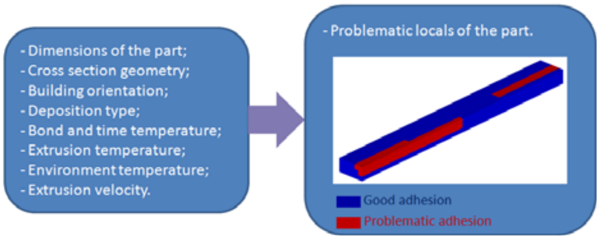


Figure 3 – Simplified flowchart of the computer code to compute the adhesion between filaments.

RESULTS

As case study, consider the part with the following geometry (Figure 4) and the processing conditions describe in Table 1.

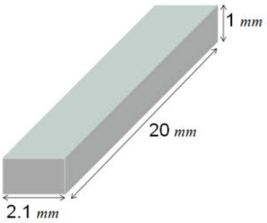


Figure 4 – Geometry of the part.

Table 1 – Processing cconditions for the adhesion test.

Property	Value
Extrusion temperature (ºC)	270
Environment temperature (ºC)	70
Extrusion velocity (m/s)	Case 1: 0.025 Case 2: 0.035
Cross section geometry	Circle
Cross section diameter (m)	0.00035
Deposition type	Unidirectional - Aligned

Figures 5 and 6 show the problematic adhesion areas of the part constructed by FFE technique, for v = 0.025 m/sec and v = 0.035 m/sec, respectively, considering that to achieve the good adhesion the temperature of the filaments must remain above 100ºC (T_{bond} = 100ºC) during at least 3 seconds (t_{bond} = 3 sec).

For the extrusion velocity of 0.025 m/sec, the program allowed us to conclude that 12% of the total volume has problematic adhesion while increasing the velocity for 0.035 m/sec the problematic adhesion areas are eliminated.

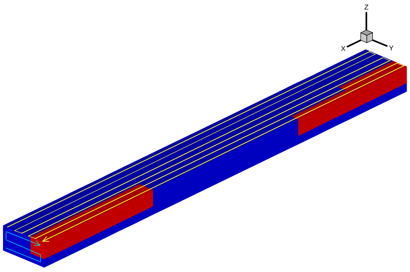


Figure 5 – Problematic adhesion areas of the part (red colour) for v= .025 m/sec.

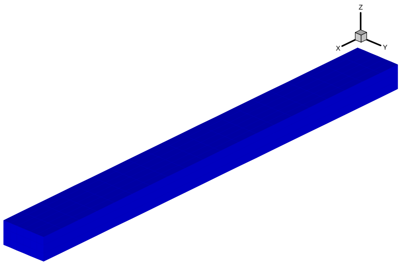


Figure 6 – Problematic adhesion areas of the part for v=0.035 m/sec).

CONCLUSIONS

This work proposed an analytical solution for the problem of modelling transient heat transfer during filament deposition in free form extrusion. A code was developed to test the adhesion quality between filaments after construction of a part by FFE. The machine variables can be modified in order to obtain a part with no problematic adhesion locals, that is, a part with the maximum mechanical resistance.

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