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

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KEYWORDS

Free Form Extrusion, Heat Transfer, Modelling, Adhesion, Bimaterial parts.

ABSTRACT

The mechanical properties of parts made by Free Form Extrusion (FFE) are controlled by the bonding degree between the individual extruded filaments. Since this adhesion mainly depends on the temperature history, an analytical heat transfer study was done and used to develop a Matlab® code, which computes the temperature evolution for a specific deposition sequence. Coupling this to an assessment parameter of adhesion quality between adjacent filaments, a new code was developed in order to establish the operating conditions that maximize the adhesion for parts made by one or two different materials.

INTRODUCTION

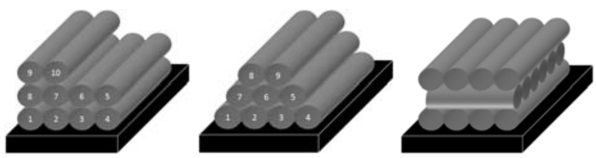
Free form extrusion (FFE) is a rapid prototyping technique, where parts are constructed layer by layer, without any mould: filaments are successively deposited following a specific trajectory in the X–Y plane controlled by the computer (according to the part geometry), the process being repeated for the required number of layers.

This sequential deposition of filaments may origin inadequate bonding between adjacent filaments, which reduces the mechanical resistance of parts: each filament must remain sufficiently hot during enough time to ensure adhesion, but simultaneously, to cool down fast enough to avoid excessive deformation due to gravity and weight of top filaments. Consequently, the knowledge of the temperature evolution of filaments with time and how this is influenced by major process variables, are fundamental.

Some investigation has been made 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. All these models have a common feature: thermal contact resistance is ignored, which avoids the devopment of a generic model. The present work expands the above efforts, by aiming at developing a transient heat transfer analysis of filament deposition, taking into account the existing physical contacts.

HEAT TRANSFER ANALYSIS

Depending on the deposition sequence, during the creation of a part by FFE each filament is subjected to the same heat transfer mechanism but with different boundary conditions, which also vary along time. The heat flux with support, with the surrounding environment, with colder filaments deposited before and with younger hotter filaments deposited afterwards were included in the energy balance. A differential equation was then obtained and 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 (Figure 1).



a) b) c)

Figure 1: Deposition sequences. a) Unidirectional and aligned; b) Unidirectional and skewed; c) Perpendicular.

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Some parts with some geometrical features may require the use of a support material, to be removed after manufacture. This possibility is considered in the algorithm for unidirectional and aligned filaments.

The knowledge of the temperature evolution along deposition time for each filament gives the possibility of obtaining relevant information about the final part quality, such as, the adhesion between the adjacent filaments: 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 MatLab® (Figure 2).

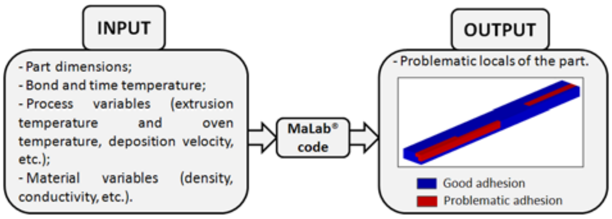


Figure 2: Simplified flowchart of the computer code to compute the adhesion between filaments.

RESULTS

As a case study, a square bottle cap with the following geometry (Figure 3) is considered and the processing conditions are described in Table 1.

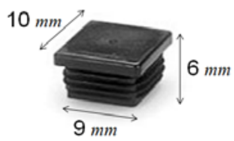


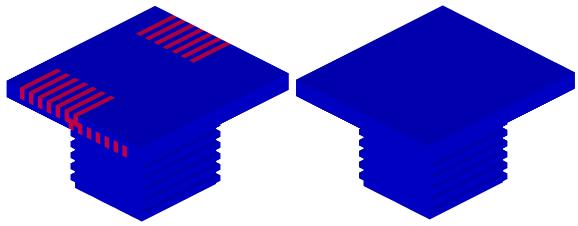
Figure 3: Geometry of the square bottle cap.

Table 1: Processing conditions for the adhesion test.

Property	Value
Extrusion temperature (ºC)	270
Oven temperature (ºC)	70 / 80
Extrusion velocity (m/s)	0.025
Cross section geometry	Circle
Cross section diameter (m)	0.0003
Deposition type	Unidirectional

Figure 4 shows the problematic adhesion areas of the part constructed by FFE technique, for T_E = 70.ºC and T_E = 80.ºC, considering that to achieve the good adhesion, the temperature of the filaments must remain above 95.ºC (T_{bond} = 95.ºC) during at least 1 second (t_{bond} = 1 sec).

According to the computation code results, for an oven temperature of 70.ºC, 6% of the total volume has problematic adhesion, but increasing the oven temperature (80.ºC), a maximized quality part is obtained.



a) b)

Figure 4: Problematic adhesion areas of the part (red colour). a) for T_E = 70.ºC; b) for T_E = 80.ºC .

CONCLUSIONS

The modelling of heat transfer in Free Form Extrusion is mandatory to determine how the adhesion can be improved between filaments. An analytical solution for this problem is proposed and used to develop a code that tests the adhesion quality between filaments after construction of a bimaterial part by FFE. The operation variables can be then modified until achievement of a high quality part, and important relationships between variables and objectives can be established.

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