

Optimization of Thermoplastic Pre-pregs Overmoulding

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Abstract. The search for new technological concepts in the field of injection of thermoplastic polymers, in order to optimize the process and reduce cycle time, faced us with a new concept in moulding, where two different technologies are proposed to be unified. The fabric impregnated with thermoplastic is an example of a quite new product that combines the potential of polymers with long reinforcing fibres. In order to process this new product, injection of polymers and thermoforming will be applied in only one operation. To allow cycle time prediction for this new technique, changes will be made in the formulation of conventional injection cycle time, in order to comprise the new necessary stages. In this work a new approach is proposed to obtain moulded parts of thermoplastic polymers with functional fabric only in a single processing cycle. The description of the new stages and its mathematical formulation is made, in function of the time needed to complete each one. The results presented come from processing parameters optimization using the Particle Swarm Optimization (PSO) algorithm.

Introduction

Pre-preg fabrics are usually processed by thermoforming techniques. In order to inject new polymer over the thermoformed fabric, a new mould is necessary, where the part is placed and then injected [1]. This technique implies the use of two different moulds and the transferring of the part between them, which was a very time and resources consumption, and a long period until a complete part is finished. The new proposed technique pretends to join the overmoulding but this time with functional instead of aesthetic fabric with the injection of thermoplastic all in a single procedure. In order to predict the cycle time, the existing formulation on the injection time was the starting point, on which the new stages were added.

Molding Cycle

Description of the process. The cycle begins with placement of the pre-preg into the mould cavity. The time required for this stage is dependent on the speed of the machine that performs it, however this procedure can be performed simultaneously. In order to guarantee the processing of the pre-preg the mould surfaces must be at a specific temperature depending on the polymeric material, T_{melt} , [2]. The mould is heated until the processing temperature, in order to promote the fibres impregnation. Next the mould is closed wedging the fabric between the mould parts. In this stage, the two main parts of the mould must squeeze the fabric to ensure total contact from both parting surfaces. To promote the adhesion of the injected polymer to the one impregnated in the fabric the mould is maintained at, T_{melt} . However is well known that the mould must be at a range of temperatures for each polymer [3]. The polymer injection is made in the traditional method comprising the filling and packing times. Next, the mould must be cold down to the ejection temperature, T_{eject} . When part reaches a safe temperature, the mould is opened, and the ejection system moves forward removing the part from the mould. Fig. 1 shows the temperature variation at each stage.

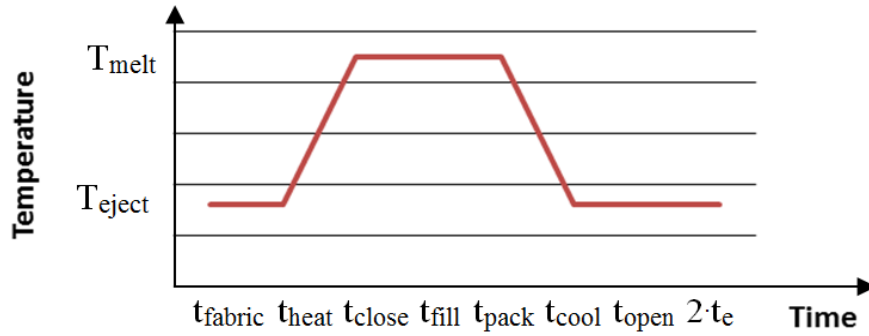


Fig. 1 – Temperature at each stage.

Stages Considered. The theoretical injection cycle time, t_c , in a conventional process is obtained from the sum of the five main stages of the process [4]. In this new approach new stages must be considered. The mathematical formulation for cycle time is presented below (1):

$$t_c = t_{fabric} + t_{heat} + t_{close} + t_{fill} + t_{pack} + t_{cool} + t_{open} + 2 \cdot t_e \tag{1}$$

Where, t_{fabric} , is time needed to place the fabric in the mould and, t_{heat} , is the time needed to heat the mould to the processing temperature. All the other remaining stages are considered the same as in the previous work [4]. The mathematical formulation for the new stages is based on the mould concept represented in fig. 2.

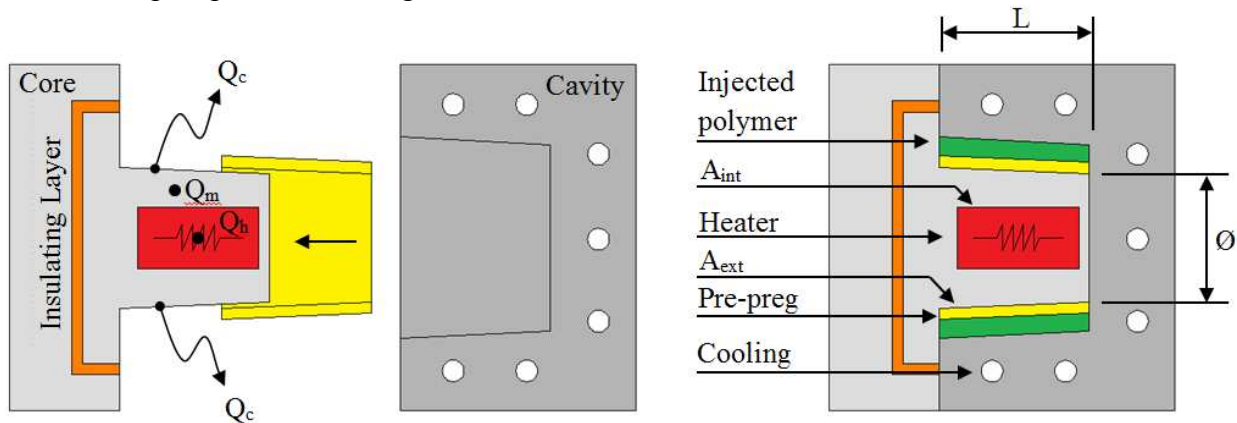


Fig. 2 – Concept of heating mould for overmoulding of composite parts.

Mathematical formulation of the new stages. The, t_{fabric} , is the time spent by the robot arm to place the fabric into position. This time is achieved by the velocity of the equipment, given by equation (2):

$$t_{fabric} = \frac{e}{v} \tag{2}$$

Where v is the robot arm velocity and e the width of the mould. The calculation of the heating time was based on an energy balance where the heat source, Q_h , is provided by a heater placed inside the core as illustrated in fig. 2. Heat flows by conductivity through core until the external face where it flows by convection to the air, Q_c . In heat transfer process, most of the generated heat energy accumulates in the mould core, Q_m , raising its temperature. The instant energy balance of the heating stage in the mould core is expressed by equation (3):

$$Q_h + Q_c = Q_m \tag{3}$$

Where Q_h is the heat generated by the heater, Q_c denotes the energy losses to the environment and Q_m represents the accumulated heat in the core. Equation (3) can be expressed in the expanded form in terms of power (4):

$$P_R + A_{\text{ext}} \cdot h \cdot (T_{\infty} - T(t)) = \rho \cdot C_p \cdot (A_{\text{ext}} - A_{\text{int}}) \cdot L \cdot \frac{dT(t)}{dt} \quad (4)$$

In the left side of the equation P_R is the heater power, A_{ext} , is the external area of the core, h is the thermal convection coefficient, T_{∞} is the temperature of air surrounding the outer face of the core and $T(t)$ is the temperature at any moment of time. In the right side ρ is the material density, C_p the specific heat, A_{int} , is the internal area of the core, that is in contact with the heater and L is the core length. Considering:

$$Q = \frac{P_R}{\rho \cdot C_p \cdot (A_{\text{ext}} - A_{\text{int}}) \cdot L} \quad \text{and} \quad m = \frac{A_{\text{ext}} \cdot h}{\rho \cdot C_p \cdot (A_{\text{ext}} - A_{\text{int}}) \cdot L} \quad (5)$$

Equation (4) is now written in following form (6):

$$Q = m \cdot \theta(t) + \frac{d\theta(t)}{dt} \quad (6)$$

Considering:

$$\theta(t) = T(t) - T_{\infty} \Rightarrow \frac{d\theta(t)}{dt} = \frac{dT(t)}{dt} \quad (7)$$

The solution for the differential equation (6) is given by (8):

$$\theta(t) = C \cdot e^{-m \cdot t} + \theta_p \quad (8)$$

Where C is the integration constant, and θ_p is the particular solution of the differential equation given by (9):

$$\theta_p = \frac{Q}{m} = \frac{P_R}{A_{\text{ext}} \cdot h} \quad (9)$$

Considering $\theta(0) = \theta_0$ at $t=0$ the constant C is given by (10):

$$C = \theta_0 - \frac{Q}{m} \quad (10)$$

The temperature at any instant of time is achieved by (11):

$$\theta(t) = \theta_0 \cdot e^{-m \cdot t} + (1 - e^{-m \cdot t}) \cdot \frac{Q}{m} \quad (11)$$

Process Optimization. The PSO algorithm was the chosen to perform the optimization process based on the results obtained in the previous research work related to injection moulding optimization [5]. The optimization process was carried out in 50 runs performing 350 cycles each, and only runs in which all results are feasible were considered. The fig. 3 shows the convergence and fig.4 the variables behavior for the 50 runs. The best cycle time achieved in this optimization was 56.6 seconds being this understood as a good result, considering that the part is produced in only one process.

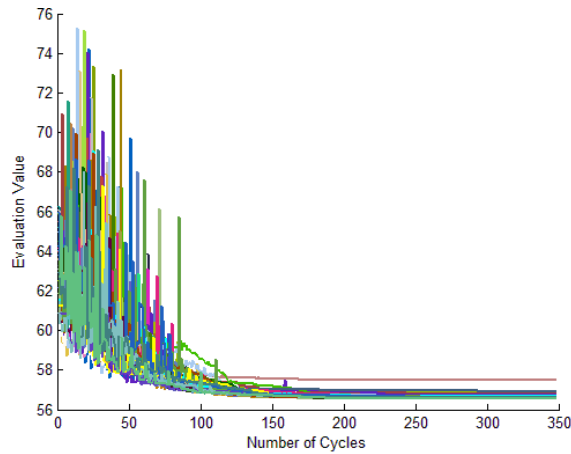


Fig. 3 – Convergence analysis.

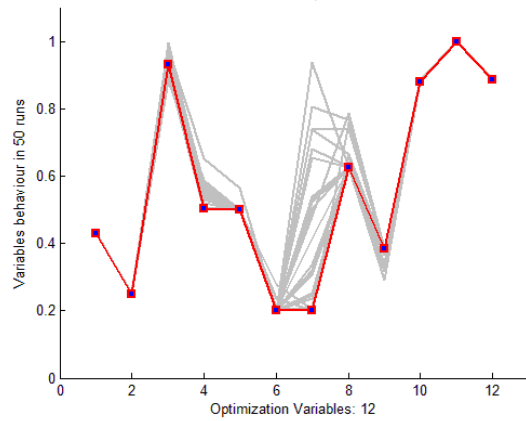


Fig. 4 – Variables behavior.

Conclusion and Future Work

The results obtained from optimization lead us to conclude that even with a long period of time for each cycle, mainly because of the gradient of temperatures between stages, the new approach is less expensive than the usual technique. The combination of the conventional techniques of overmoulding aesthetic fabric and polymer injection, give us the ability to obtain a part with multiple functionalities in a single process, reducing time and resources. And as it is well known the reduction of time in injection processes is a key issue as it strongly determines the cost per part. For future works, the mould will be equipped with sensors, monitoring the complete cycle, in order to obtain a typical curve of heating and cooling, enabling the prediction of future processes in the same conditions. Also the optimization process will be more exhaustive using not only PSO, but also Genetic algorithms among others.

Acknowledgments

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References

- [1] Laminates, Bond. Tepex superior in motion. Bond Laminates. <http://www.bond-laminates.com/en>, (2012).
- [2] Shappe. TPFL prepregs. <http://www.schappe.com/>, (2012).
- [3] Goodship, V. 2004. Practical guide to injection molding - Arburg. s.l.: A, 2004. 1-85957-444-0.
- [4] Ramos, C.; Carreira, P.; Bártolo, P and Alves, N. Optimalmould - part II: Global optimization of the injection moulding cycle time, Proceedings of the 10th International Conference of Numerical Analysis and Applied Mathematics, Editor(s): Theodore E. Simos, et al., Vol. 1479, pp. 1574-1578, American Institute of Physics, (ISBN: 978-0-7354-1091-6), (2012).
- [5] Carreira, P. ; Ramos, C.; Bártolo, P and Alves, N. Bio inspired algorithms for Injection Moulding Optimization, Advanced Materials Research Vol. 683 pp 771-774 (2013).