NUMERICAL PROCESS SIMULATIONS FOR INDUSTRIALLY PULTRUDED PROFILES

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Introduction

Pultrusion is a practical and continuous composite manufacturing process for producing any constant cross sectional profiles at any length. A schematic view of the pultrusion process is depicted in Fig. 1. The reinforcements are impregnated in a resin bath and the composite is cured inside a heating die in which an exothermic reaction takes place for the thermosetting resin matrix.

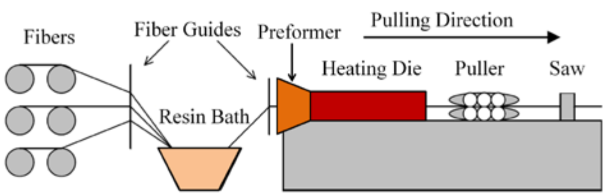

Figure 1. Schematic view of a pultrusion process.

Recently, thermo-mechanical analyses of the pultrusion process has been carried out [1, 2] in which the process induced residual stresses and distortions have been investigated. In pultrusion, generally E-glass fiber reinforcements typically in the form of continuous uni-directional (UD) rovings or continuous filament mat (CFM) are used. A CFM consists of long continuous lengths of glass fiber overlaying each other in a totally random swirl-like pattern to form a more open textured and stronger reinforcement. Therefore it is highly suitable for pultrusion process. In the present work, two different pultruded profiles are considered: an L-shaped and a reactangular (hollow) profile. A glass/polyester is used for the UD and the CFM layers. The spring-in and warpage formations are predicted for the L-shaped and the rectangular profiles, respectively.

Problem Description

A schematic view of the 3D thermo-chemical model is depicted in Fig. 2 and Fig. 3 for the L-shaped and the rectangular profile, respectively. A glass/polyester is considered for the UD and the CFM layers and chrome steel is used for the die. The details of the pultrusion set-up are provided by a commercial pultrusion company. The lengths of the heating die and the post-die region are specified as 1 m and 5 m, respectively. The exterior surfaces of the part except those in contact with the die are exposed to ambient temperature (27 °C) with a convective heat transfer coefficient of 10 W/m-K. Similar convective boundaries are defined for the exterior surfaces of the die except the heating areas shown in Fig. 2 and Fig. 3. The temperature is assumed to be equal to the resin bath temperature (27 °C), while the matrix material is assumed to be totally uncured at the inlet of the die. A perfect thermal contact is assumed at the die-part interface. The curing kinetics of the polyester are obtained from the isothermal and dynamical differential scanning calorimetry (DSC) tests.

In the 2D quasi-static mechanical analysis, generalized plane strain elements are used in ABAQUS. The cross sectional details are given in Fig. 4 and Fig. 5 for the L-shaped and the rectangular profile, respectively. The cross section of the composite is moved through the pulling direction during the process meanwhile tracking the corresponding temperature and degree of cure profiles already calculated in the 3D thermo-chemical analysis [1]. The corresponding process induced distortions and stresses are then calculated in the 2D mechanical model.

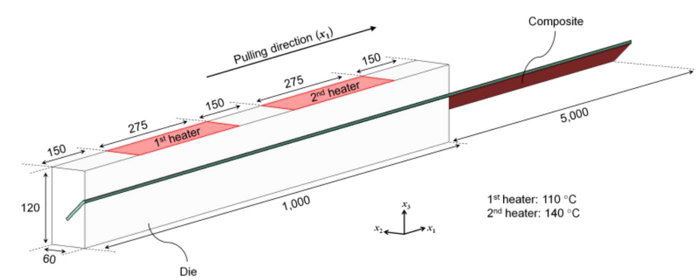

Figure 2. Schematic view of the half model for the pultrusion of the L-shaped profile.

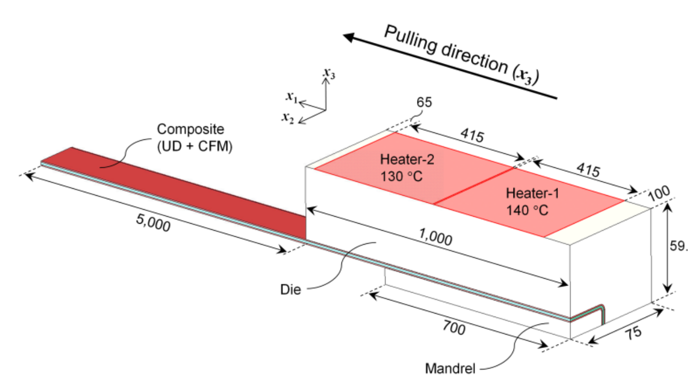

Figure 3. Schematic view of the quarter model for the pultrusion of the rectangular hollow profile.

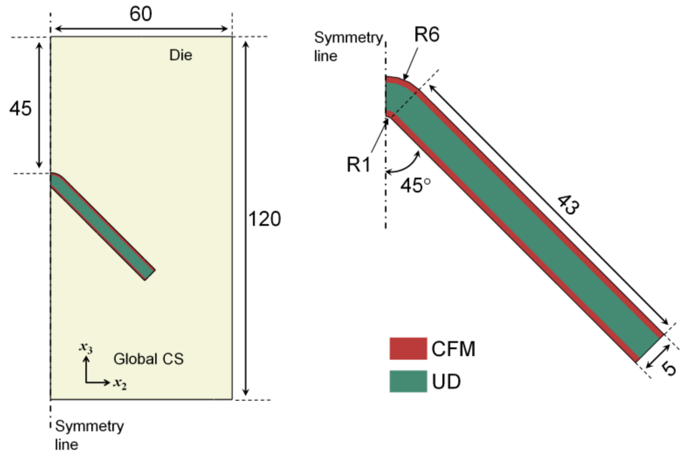

Figure 4. The details of the cross section for the L-shaped profile.

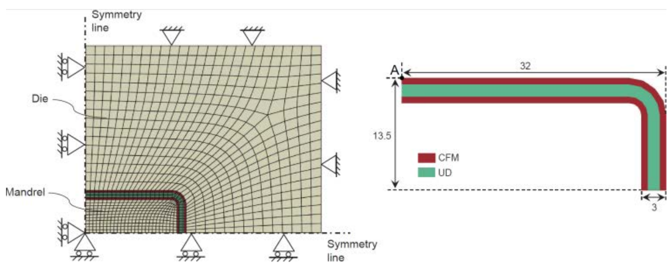

Figure 5. The details of the cross section for the rectangular hollow profile.

Results and Discussion

The process induced distortions are calculated using the temperature and degree of cure distributions obtained in the 3D thermo-chemical analysis. The deformed contour plot of the part and the displacement (U_3) values in the x_3-direction are depicted in Fig. 5 and Fig. 6 for the L-shaped and the rectangular profile, respectively. It is seen that a spring-in and a warpage formations are found to prevail for the L-shaped and the rectangular profile, respectively.

The spring-in angle is calculated approximately as 0.5° which agrees quite well with the measured one for the real pultruded part. The warpage is predicted approximately as 1.4 mm as shown in Fig. 7 for the rectangular hollow profile at the end of the process. These unwanted spring-in and warpage formations in pultrusion directly affect the geometrical tolerance of the pultruded parts as well as the internal stress level. The proposed numerical simulation tool for the pultrusion process can be further used to minimize the spring-in angle or warpage as well as maximizing the production rate.

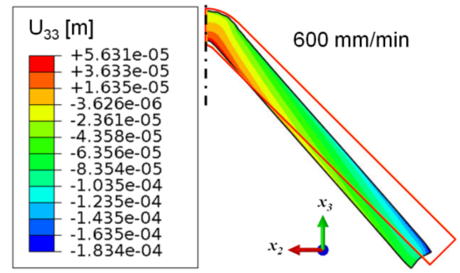

Figure 6. The deformed contour plot of the L-shaped profile in the x_3-direction. Scale factor for the deformed shape is 10.

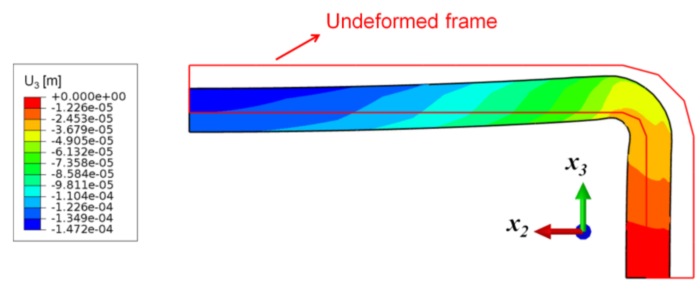

Figure 7. The deformed contour plot of the rectangular hollow profile in the x_3-direction. Scale factor for the deformed shape is 10.

Conclusion

In the present work, thermo-chemical-mechanical analyses of the pultrusion of an industrial L-shaped and rectangular hollow profile were performed. A glass/polyester composite was considered for the UD and the CFM layers. The temperature and the degree of cure were calculated in the 3D thermo-chemical analysis. Afterwards, these profiles were mapped to the 2D quasi-static mechanical analysis in which process induced stresses and distortions were obtained. The spring-in and the warpage formations at the end of the process were predicted and the results were found to agree well with the measured ones in the real industrially pultruded products.

References

[1] Baran I, Tutum CC, Nielsen MW, Hattel JH. Process induced residual stresses and distortions in pultrusion. Compos Part B: Eng 2013; 51:148-161.

[2] Baran I, Tutum CC, Hattel JH. The internal stress evaluation of the pultruded blades for a Darrieus wind turbine. Key Engineering Materials 2013; 554-557: 2127-2137.