INVESTIGATION OF THE THERMAL CONTACT RESISTANCE IN THERMOSETTING PULTRUSION PROCESS

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Introduction

Pultrusion process is one of the most effective methods for production of composite materials with having constant cross-sectional profiles such as beams, stiffeners, tubes etc. This process has been widely used for manufacturing highly strengthened and continuous composite structures. The fascinating point of the pultrusion process is the productivity and low cost. A schematic view of the pultrusion process can be seen in Fig. 1.

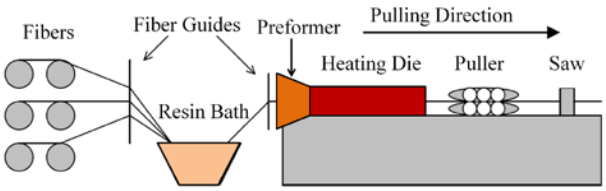

Figure 1. Schematic view of a pultrusion process.

In recent years, several experimental studies and numerical simulations for the pultrusion process have been performed in order to investigate the effects of the process parameters on the quality of manufactured part and the productivity of the process [1-6]. In the present study the control volume based finite difference (CV/FD) method is utilized to perform thermo-chemical simulation of the pultrusion process of a composite rod. Preliminary, the model is applied for a simple setup without die and heaters and the results match well with those obtained experimentally in the literature [6]. In order to study the effects of the thermal contact resistance (TCR), which can also be expressed by the heat transfer coefficient (HTC), on the pultrusion process, a cylindrical die block and heaters are added to the original problem domain. The significance of using the TCR in the numerical model is investigated by comparing constant and variable TCR (i.e. position dependent) at the interface.

Problem Description

A cylindrical die block is added to the validated pultrusion domain [6] together with three cylindrical heating pads mounted on top of it. The graphite fiber reinforcement (Hercules AS4-12K) and epoxy resin (SHELL EPON9420/9470/537) system are used for the composite and steel is used for the heating die. A schematic view of the die, the composite and the heaters is seen in Fig. 2. The set temperatures of the heaters are given in [6] from left to right as 171-188-188 °C, but the location and the length of the heaters are not given. The boundary conditions for the composite part are assumed to be the same as in [6] except at the die-part interface where the non-perfect thermal contact between the die and the composite is now modeled by a TCR. For the die block all the exterior surfaces except those on which the heating pads are located are exposed to the ambient temperature (27 ^{o}C) with a convective heat transfer coefficient of 10 W/m^2 K. Since it is not given in [6], cooling channels located at the initial die section are not considered in this model.

In order to obtain the same centerline temperature profile of the composite within this new pultrusion simulation domain, a curve fitting procedure is performed using the data composed of 15 centerline temperature values measured from [6] by equally spaced thermocouples. The TCR values (design variables in the curve-fitting procedure) are predicted by minimizing the difference between the measured ([6]) and the calculated (the new configuration) centerline temperatures, i.e. $\sum(T_{meas}-T_{cal})^2$, for certain die radii. The temperature curve fitting procedure is repeated with 5 different die radii (r_d) selected as 10, 25, 50, 75 and 100 mm, there by considering possible die designs for the composite rod given in [6]. Two different optimization case studies are performed:

a) Constant TCR (Case-1): In this case study only a single TCR value (one design variable) through the axial direction is optimized to minimize the error, $\sum(T_{meas}-T_{cal})^2$. A schematic view of the single TCR case can be seen in Fig. 2.

b) Variable TCR (Case-2): In this problem 9 equally spaced (each of □100mm) TCR regions are defined along the interface. The configuration of the variable TCR regions can be seen in Fig. 2.

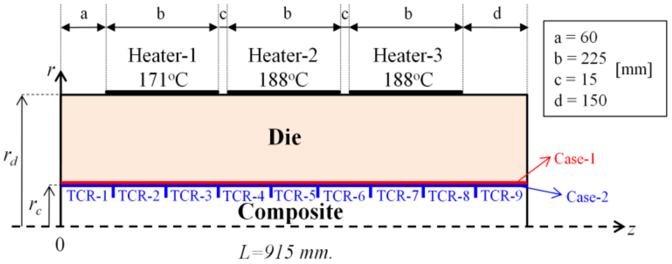

Figure 2. Schematic representation of the pultrusion domain of the composite rod including the cylindrical die block and the heaters with TCR regions.

Results and Discussion

The optimum TCR values for the predefined die radii are shown in Fig. 3 (top) and Fig. 3 (bottom) for Case-1 and Case-2, respectively. According to Fig. 3 (top), as the die radius increases the constant TCR value used in Case-1 also increases which shows that the total amount of heat input is increased. It is seen from the shape of the curves in Fig. 3 (bottom) that the behavior or characteristics of the variable TCR regions defined in Case-2 is similar for all the die radii used. There is a decreasing trend in the TCR values for the initial regions; however for the last region this trend is reversed. It must be noted that the TCR values are strongly dependent on the pultrusion domain, i.e. the location and the temperature of the heaters, the die geometry, the pressure inside the die, inlet temperature etc.

The optimum TCR values for both cases, i.e. the minimum error ($\sum(T_{meas}-T_{cal})^2$) values, are found to be 6957.5, 7979.8, 8250.7, 297.5 and 8275.9 in Case-1 and 6.7, 5.2, 3.7, 7.4 and 19.4 in Case-2 for the die radii of 10, 25, 50, 75 and 100 mm, respectively. The minimum error for Case-1 in which a single TCR is used is significantly higher than the error for Case-2 with respect to all die radii. For instance the centerline temperature and the cure degree profiles of the composite rod for a die radius of 10 mm are seen in Fig. 4 (top) and Fig. 4 (bottom), respectively. The temperature and the cure degree profiles obtained with the use of variable TCRs are almost the same as those obtained in the validation case. However the results obtained by using a single TCR deviate considerably with respect to the centerline temperature and the cure profiles of the composite rod.

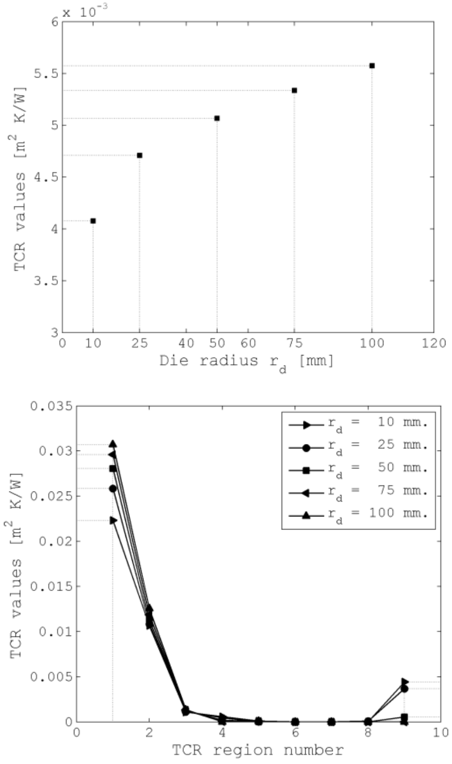

Figure 3. Optimum constant TCR values found in Case-1 (top) and optimum variable TCR values found in Case-2 (bottom) at the interface for different die radii.

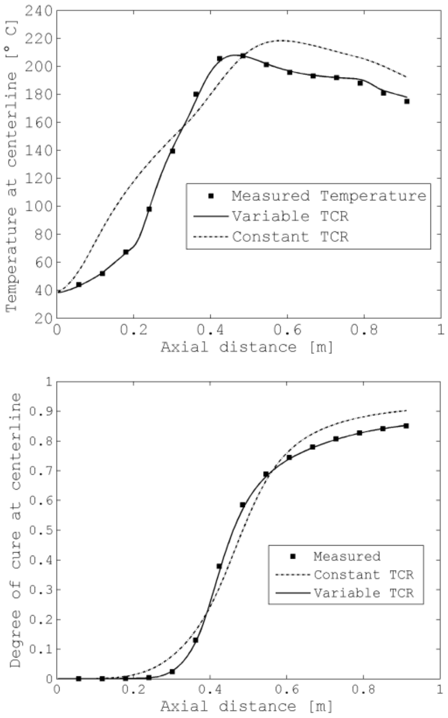

Figure 4. The steady state centerline temperature (top) and the cure degree (bottom) distributions obtained by using single and variable TCR at the interface.

Conclusion

In the present study a numerical model for the simulation of pultrusion of a composite rod is presented. In order to obtain the same centerline temperature in [6] for the new configuration (i.e. including the die block and the heaters) the TCR was taken into account for predicting the same temperature profiles. The application of variable TCRs gave much better results than the application of a single TCR at the interface. In addition to that the TCR takes the role of the shrinkage and also the cooling channels which are not included in the numerical model. It is also concluded that the TCR has an important effect on the deterministic thermo-chemical simulation of the thermosetting pultrusion process.

References

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