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SIMULATION AND ANALYSIS OF HEAT TRANSFER AND CURE PROGRESSION IN THE PULTRUSION OF THERMOPLASTIC COMPOSITES

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INTRODUCTION

Pultrusion is an efficient and continuous manufacturing process used to produce fiber-reinforced composite profiles with constant cross-sections. In this process, continuous fibers are impregnated with a polymer resin, shaped through a forming system, and cured inside a heated die. Despite its widespread industrial use, several key aspects of the pultrusion process such as heat transfer, cure kinetics, pressure development in the tapered die region, and the impregnation behavior of thermoplastic-reinforced fibers are still not fully understood.

This paper aims to address these knowledge gaps by combining experimental investigations with advanced computational modeling.

METHOD

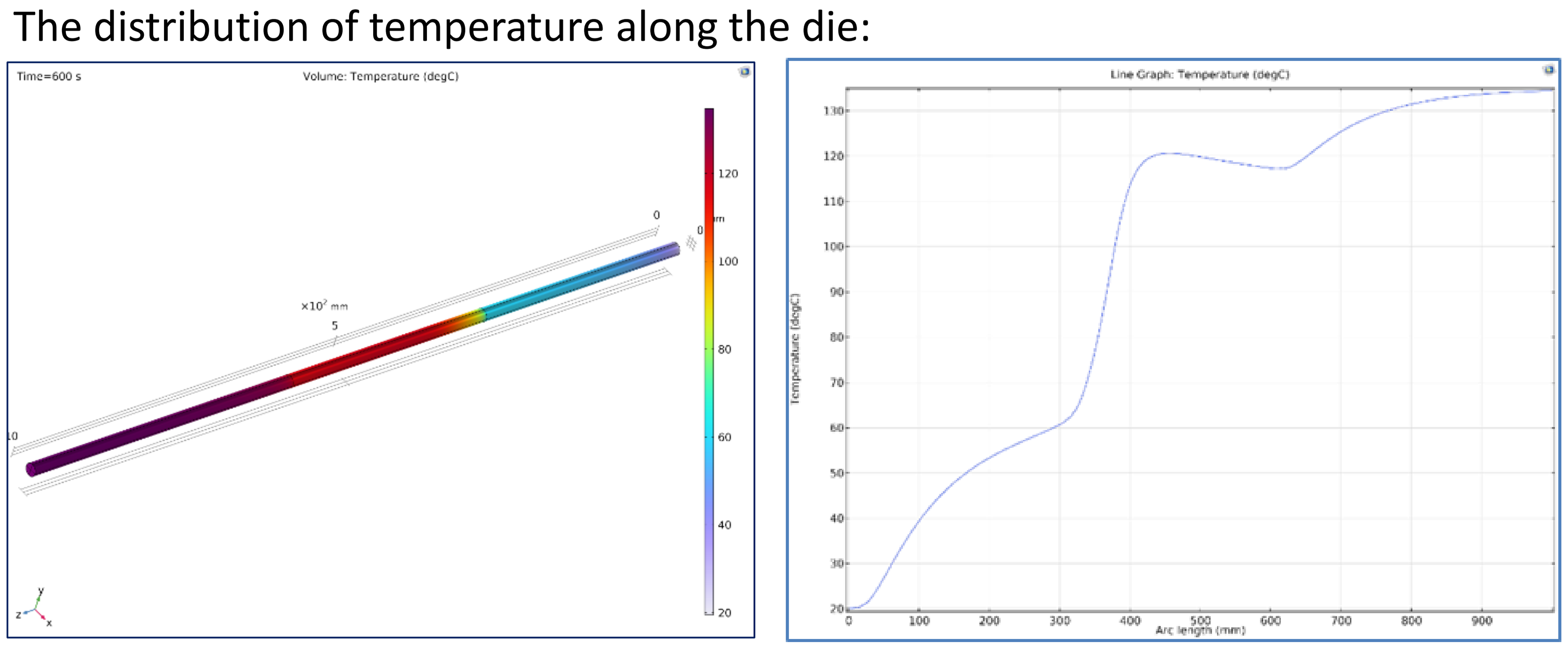
For the experimental part we have used Elium® C599 E resin supplied from Arkema which is a liquid acrylic polymer blended with reactive monomers and processing additives. This type of resin is developed for processes that require extended open time, such as pultrusion or filament winding with a resin bath system, and has a medium viscosity for optimum fiber impregnation. It is highly compatible with glass, carbon, and natural fibers, improving wettability and maximizing the final performance of the composite.

The resin's cure kinetics were characterized using both dynamic and isothermal differential scanning calorimetry (DSC), providing detailed insights into its polymerization behavior.

Based on these experimental results, a thermochemical model of the pultrusion process was developed using COMSOL Multiphysics®. The model incorporated heat transfer, cure kinetics, die geometry, heating zones, pulling speed, and material properties to realistically simulate the resin and composite behavior inside the die. Simulation outputs, including temperature distribution, degree of cure, and resin flow behavior, were visualized through charts and contour plots. These results were used to identify optimal processing conditions, ensuring complete curing while maintaining high production efficiency. Finally, the computational model was validated against the experimental DSC data to confirm its accuracy and predictive capability.

RESULTS AND DISCUSSION

The distribution of temperature along the die:



The numerical simulations provided detailed insights into the curing behavior of Elium®-based thermoplastic composites during pultrusion. Temperature profiles along the die revealed the presence of thermal hotspots near the die walls, where heat transfer is most intense. The simulation results showed that the curing process initiates at the die walls and gradually propagates toward the core of the profile. This pattern is consistent with the expected heat transfer-driven curing mechanism in thermoplastic composites.

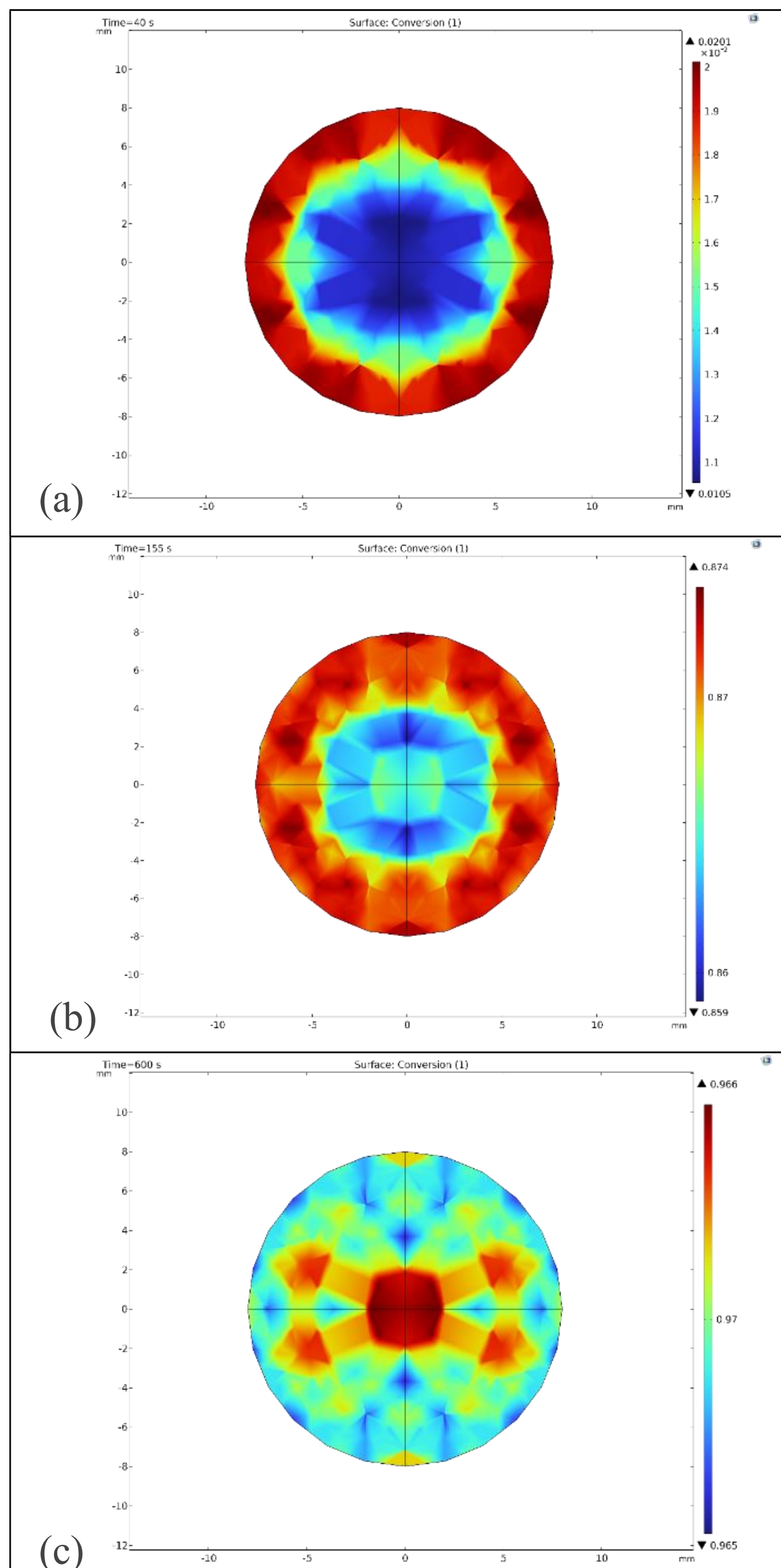


Fig. 2 The distribution of curing at different position along the die: a)66 mm b)260mm c)1000 mm

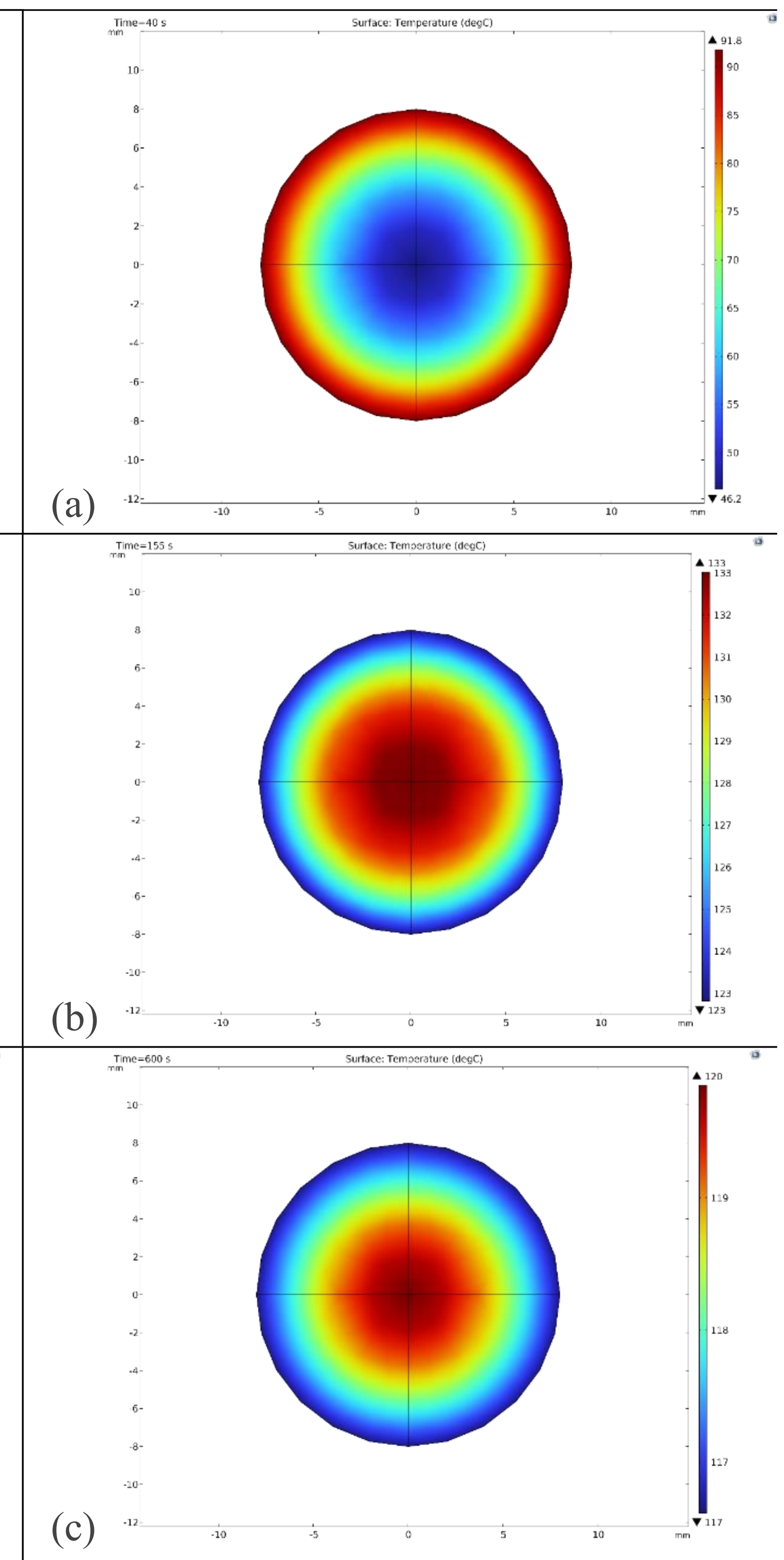


Fig. 3 The distribution of temperature at different position along the die: a)66 mm b)260mm c)1000 mm

The predicted degree of cure along the die length indicated that complete curing occurs approximately 700 mm from the die inlet, which closely matches experimental observations obtained from DSC measurements and pultruded samples. Across the cross-section, the center of the profile lags behind the edges in the curing process, highlighting the importance of die design and heating strategies in achieving uniform curing.

CONCLUSION

By comparing simulation outputs with experimental data, the model was successfully validated, demonstrating its capability to accurately predict temperature distribution and the progression of cure. The results also allowed the identification of optimal process parameters, such as die heating zones and pulling speed, which can be adjusted to avoid thermal hotspots and ensure consistent composite quality.

Overall, the combined experimental and computational approach provided a deeper understanding of the pultrusion process for Elium® composites and offered a reliable tool for process optimization. The findings emphasize the critical role of coupling heat transfer and cure kinetics in numerical models to capture the complex behavior of thermoplastic composites during processing.

REFERENCES

Minchenkov, K., Gusev, S., Sulimov, A., Alajarmeh, O., Sergeichev, I., & Safonov, A. (2023). Experimental and numerical analyses of the thermoplastic pultrusion of large structural profiles. *Materials & Design, 232*, 112149.

Kazemi, S., et al. (2020). Experimental and computational analysis of the polymerization overheating in thick glass/Elium® acrylic thermoplastic resin composites. *Composites Part B: Engineering.*