Modeling of Thermoplastic Composite Filament Winding

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(Abstract)

Thermoplastic composite filament winding is an on-line consolidation process, where the composite experiences a complex temperature history and undergoes a number of temperature history affected microstructural changes that influence the structure's subsequent properties. These changes include melting, crystallization, void formation, degradation and consolidation. In the present study, models of the thermoplastic filament winding process were developed to identify and understand the relationships between process variables and the structure quality. These include models that describe the heat transfer, consolidation and crystallization processes that occur during fabrication of a filament wound composites structure.

A comprehensive thermal model of the thermoplastic filament winding process was developed to calculate the temperature profiles in the composite substrate and the towpreg temperature before entering the nippoint. A two-dimensional finite element heat transfer analysis for the composite-mandrel assembly was formulated in the polar coordinate system, which facilitates the description of the geometry and the boundary conditions. A four-node 'sector element' was used to describe the domain of interest. Sector elements were selected to give a better representation of the curved boundary shape which should improve accuracy with fewer elements compared to a finite element solution in the Cartesian-coordinate system. Hence the computational cost will be reduced. The second thermal analysis was a two-dimensional, Cartesian coordinate, finite element model of the towpreg as it enters the nippoint. The results show that the calculated temperature distribution in the composite substrate compared well with temperature data measured during winding and consolidation. The analysis also agrees with the experimental observation that the melt region is formed on the surface of the incoming towpreg in the nippoint and not on the substrate.

Incorporated with the heat transfer analysis were the consolidation and crystallization models. These models were used to calculate the degree of interply bonding and the crystallinity achieved during composite manufacture. Bonding and crystallinity developments during the winding process were investigated using the model. It is concluded that lower winding speed, higher hot-air heater nozzle temperature, and higher substrate preheating temperature yield higher nippoint temperature, better consolidation and a higher degree of crystallization. Complete consolidation and higher matrix crystallization will result in higher interlaminar strength of the wound composite structure.