# Analysis of Thermal Residual Stresses during the Cure of Composite Parts Manufactured by Resin Transfer Molding

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## ABSTRACT

As the composite industry keeps growing, thick parts and pieces of complex shape have become more common. Composite components for structural applications require larger cross-sections than non-structural ones. The curing of thick parts is a challenge because of the low thermal conductivity of the composite and high heat of reaction during the cross-linking polymerization. This combination of high thermal resistance and large heat source in the part during cure leads to significant thermal gradients and generates residual stresses that may result in polymer degradation. In order to improve the quality of thick composites, the processing temperature needs to be controlled so that thermal gradients remain small. This means that the cure temperature needs to be lower than for thin parts. At low temperature resin kinetics may be considerably different from what is observed at a higher temperature. From a chemical point of view, the reinforcing fibers are not affected during the process cycle, but the polymer matrix can shrink during cross-linking by as much as 7%. In addition to chemically induced deformation, thermal dilatation also comes into play. The small thermal expansion coefficient of the fibers along their longitudinal axis produces little deformation during cool-down. However, the polymer matrix exhibits a higher thermal expansion and is more affected by temperature changes. During processing, these deformations are balanced internally in the composite and residual stresses are induced. Residual stresses during the cure of fiber-reinforced composites play a significant role on mechanical properties and generate warpage, matrix cracks or delamination. Thick parts are usually too rigid to relieve residual stresses by distortion, so internal damage is more likely to occur in this case. The processing of thick composites at a lower temperature should reduce thermally induced residual stresses. However, a minimum temperature must be reached before the cross-linking reaction begins. At a lower temperature cure takes a longer time and the number of links created may not be enough to obtain the required mechanical properties. In composite manufacturing by RTM (Resin Transfer Molding), time, temperature and pressure are the most relevant process parameters. A proper selection of these parameters is essential to ensure successful molding and obtain controlled properties in the part. A finite difference analysis is implemented to simulate the effect of thermal gradients through the thickness of the part and model the variations of the visco-elastic properties of the polymer during cure. Residual stresses are calculated through the thickness of the composite and as a result, optimal curing strategies can be devised. Numerical simulations are compared with experiments for a series of composite samples manufactured by RTM. Finally, a thermal optimization algorithm is developed to improve part curing and prevent resin degradation and composite delamination.