

Characterization of Phenolic Resins and Their Co-Cure with Other Matrix Resins

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This work is directed towards studying the phenolic resin system and its compatibility with other matrix resins used for composite manufacture. Phenolic resins are an integral part of multi-layered composites in applications like Army tanks and aircraft where fire resistance is a critical requirement. Co-injection Resin Transfer Molding (CIRTM) is a new technique developed at the University of Delaware's Center for Composite Materials (UD-CCM) in collaboration with the Army Research Laboratory (ARL) that enables the manufacture of multi-layered hybrid composite parts in a single step. In CIRTM, two or more resins are simultaneously injected into a mold filled with a stationary fiber bed.

One of the most common methods of reducing the viscosity of phenolic resins to facilitate injection- and mold filling is adding water as a diluent. Although it is very effective in controlling the viscosity, evaporation of water from the resin during cure has been found to cause micro-voids 8-10 microns in size in the cured resin. The presence of micro-voids is believed to affect the properties of the final product. Thus, the first part of this thesis contains a study of the effects of parameters like cure temperature, post-cure temperature, catalyst concentration, and diluent on the changes in micro-void distribution and consequently the properties of phenolic resin. It has been shown that modification of the resin by removing the initial water and adding ethylene glycol instead has the most significant effect on the micro-voids as well as the properties of the polymer. A lower void content along with an increase in density has been observed along with a significant improvement in the mechanical properties like flexural modulus and fracture toughness of the modified resin.

CRTM not only reduces labor costs and manufacturing time but also offers the potential of better integrated structure due to the formation of a tougher interphase through co-cure of resins. These advantages are, however, dependent on the successful co-cure of the resins involved; hence, there exists a need to determine compatible resin systems for co-injection. Thus, the focus of the second part of the thesis is on determining mutual interactions of phenolic resins with other matrix resins in order to gain insight into the behavior of the interphase between them. Extensive use of FTIR spectroscopy, DSC, and DMA has been made in these studies. It was found that the cure of vinyl-ester is strongly inhibited in the presence of phenolic resins; therefore, it is advisable to have an impermeable separation layer in between these two systems. In the case of epoxy-amine and phenolic co-cure, it was found that an interpenetrating network of phenolic-amine and epoxy-amine chains causes a decrease in the crosslink density, significantly lowering the T_g. A model to quantify the effect of phenolic resin on the cure of epoxy-arnines has been proposed. It has been demonstrated that increasing the initial amine concentration in the co-cure reaction mixture accordingly leads to an increase in the epoxy conversion as well as the T_g of the material.