An Innovation in Manufacturing Advanced Composites: Thermal Press Curing

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ABSTRACT

Curing and consolidating thermoset composite laminates typically involves vacuum bagging an uncured and formed layup over a net shape mold, placing it in an autoclave, and subjecting the entire unit to temperature, vacuum, and pressure cycles as prescribed by the material manufacturer. Autoclaving is generally considered the major bottleneck in manufacturing advanced composite parts because of high capital and consumable costs, energy usage, waste generated, and process scalability.

An alternative process to autoclaving, called Thermal Press Curing (TPC), is proposed, whereby an uncured composite laminate is pressed between a heated curing mold (tool mold) and a customized rubber-faced mold (base mold and rubber mask) that are designed to provide uniform temperature and pressure conditions. TPC was demonstrated by designing two complex 3-D part geometries: a 'benchmark' geometry based on an industry part, and a kayak paddle. A simple computational algorithm was used to derive the required tool shapes. An in-depth discussion focuses on the theoretical framework behind designing TPC tool sets including, design choices and the optimization algorithm required to design the base mold and rubber mask, optional modeling of the tool mold to verify minimal temperature gradient across the composite part, and additional manufacturing considerations.

A comparative study was performed using a 'benchmark' geometry for a part made from four plies of woven carbon/epoxy prepreg material. Identical laminates were pre-formed by double diaphragm forming and then cured and consolidated by autoclaving, Quickstep, and TPC using standard industry practice. Results of the study indicate that the TPC part is of similar quality as compared to those made by autoclaving and Quickstep, but, more importantly, requiring significantly less energy and resource consumption, lower cost (capital and recurring), and less preparation and cycle time.

A second study was performed with the kayak paddle geometry for a part made from eight plies of woven carbon/epoxy prepreg material and formed by double diaphragm forming. The study aimed to expound on the narrow body of knowledge of TPC through 3 main objectives: to experimentally compare TPC cured parts to a benchmark autoclave process, to evaluate the necessity of vacuum bagging of TPC cured parts, and to characterize the robustness/sensitivities of pressure application during the

TPC process by varying both the total pressure applied to the base mold and the location the hydraulic press ram applied pressure to the base mold.

It was demonstrated that TPC met or in most cases exceeded the part quality of the kayak paddle parts consolidated and cured by autoclaving, since for this specific part geometry, the manufacturer specified autoclave procedure followed was not able to produce an acceptable (commercially viable) part while TPC was. The author suggests this may be due to a 'pressure intensifier' effect with TPC that dynamically applies more pressure to thicker than nominal and less pressure to thinner than nominal areas on the part resulting in superior dimensional tolerances than autoclave cured parts. Measured fiber volume fractions, and void volumes indicate that TPC had superior consolidation. A vacuum bagging comparison study established there was almost no difference between TPC cured kayak paddles with or without vacuum bagging. Finally, the set of experiments that characterized the robustness/sensitivities of pressure application during the TPC process indicate that inaccuracies can have a large effect on the dimensional tolerances of the final part. In general, applying too much pressure had a minor effect while applying too little pressure or applying pressure in the incorrect location on the base mold resulted in a significantly inferior part.

In summation, TPC has been demonstrated to be commercially viable, with TPC cured parts meeting or exceeding part qualities of the current industry standard processes and without vacuum bagging. The process is likely to be of interest to industry as it has been demonstrated that the capital equipment and consumable costs are low, processing time can be held to material system minimums and it is a more environmentally friendly process due to low energy and consumable usage.