ABSTRACT

Composite materials are becoming increasingly popular due to their unique blend of properties, including very high specific stiffness and strength. Woven composites have been the subject of recent study because of their increased through-thickness strength and stiffness when compared to traditional plied composites. This increase in through-thickness properties comes at the cost of a more complex material geometry. Woven composites have complex fiber geometries, as the fibers bend around each other. This means that the manufacturing, microstructure, mechanical properties, and failure modes of woven composites are influenced not only by the constituent fiber and matrix, but also by the pattern and geometry of the weave. Systematic experimental data isolating the effects of material versus weave pattern are relatively scarce.

The aim of this study is to present a controlled comparison between two materials manufactured out of the same fibers and matrix. The only difference between the two materials is that in one case, the fibers are woven, and in the other, layers of unidirectional fiber are laid up in a traditional plied structure. With the unidirectional-fiber plied material serving as a base reference, the effect of the weave geometry on manufacturing, microstructure, mechanical properties and failure of the material is isolated and studied. Two woven carbon fiber cloths were selected for this study. One was a pseudo unidirectional weave with 12k Toray T700SC warp fibers and sticky string as the fill. The second was 2x2 twill weave, again woven out of 12k Toray T700SC. Two layer bidirectional coupons and four layer unidirectional $[0/90]_2$ coupons were manufactured using the vacuum infusion method. In this method of fabrication the fabric and consumables are laid up dry and placed under a vacuum. An inlet tube is then opened and the resin flows in and impregnates the fibers. The resin used for all samples was a 700 cps infusion resin. The rate at which resin flows through the fibers is influenced by the fiber geometry. Thus even with the same materials and same infusion parameters, the uniaxial and woven fibers result in different material densities, fiber volume fractions, and microstructural defects. The vacuum level was varied to study the effect of vacuum strength in the two types of composite.

Samples of the composites were cut using a water jet to achieve clean edges and avoid fiber damage which results from traditional machining methods. The resulting fiber volume fraction of samples of each type of composite were measured using multiple methods. Chemical digestion of the matrix was used based on ASTM –3171 to obtain a reference value for the bidirectional specimens. For other specimens, fiber volume fractions were determined using both a bulk buoyancy method, and an examination of micrographs of sections of the materials. The micrographs also permitted detailed examination of manufacturing defects resulting from varying infusion vacuum levels. Through a comparison of the two sets of results, the effects of fiber geometry on manufacturing were examined.

Standard tensile coupons of both types of composite were manufactured and cut using water jets. two layer bidirectional coupons and four layer unidirectional $[0/90]_2$ coupons were manufactured and tested to determine material properties such as elastic modulus, failure strength, and the Weibull Modulus for the distribution of failure strengths.

Unidirectional plied composites on average were stiffer and had a higher failure strength than the woven composite. They were also more reliable, as predicted by the Weibull Modulus. Failure modes in the two materials were examined and compared, both from a macroscopic and microscopic perspective. The unidirectional composite exhibited more dramatic failure behavior, with the material splintering and flying away at fracture, while failures in the woven composite were more subdued and controlled.

Implications of the experimental work for manufacturing and use of woven composites are discussed.