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Original Article

Influence of double-diaphragm vacuum compaction on deformation during forming of composite prepregs

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ABSTRACT

During the diaphragm forming process, a vacuum seal is applied between the upper and lower diaphragms to compact and hold the laminate. Therefore, a thorough characterization of the in-plane shear behavior of fabrics under diaphragm forming conditions must take into account the effect of vacuum-sealing and compaction between the two diaphragms during bias extension. The study presented here examined the shear angles of out-of-autoclave 8-harness satin woven carbon/epoxy prepregs under diaphragm compaction. A bias extension test was conducted to study the effect of diaphragm compaction and ply interactions on shear properties. The test was performed at different compaction levels, and changes in shear angle with respect to vacuum levels and diaphragm compaction forces were observed. The contribution of diaphragm material and ply interaction to shear stiffness was evaluated and compared with results from a direct bias extension test. The samples were tested at both room temperature and at elevated temperatures using a radiant heater. The results show that shear angle decreases significantly as vacuum pressure and compaction is applied between the two diaphragms. This finding indicates that vacuum levels and compaction forces have a significant influence on the deformation limit and wrinkling onset during the diaphragm forming process.

1. Introduction

Conventional composite manufacturing techniques, such as hand lay-up, are labor intensive, costly and efficient only for small production runs. In order to automate the composite manufacturing techniques and reduce processing costs for the aerospace industry, alternative approaches, such as the resin-transfer molding, stamping, and diaphragm-formation processes, have been developed.

Double-diaphragm forming, which was initially applied to thermoplastic matrix composites, is one of the most important sheet-forming processes for composite materials. A typical double-diaphragm forming process consists of three steps [1]. A flat laminate must first be placed between two deformable sheets known as diaphragms, which are themselves clamped over a forming box. The space between the diaphragms is subjected to a full vacuum seal. Next, the laminate between the diaphragms is heated up to processing temperature. Finally, controlled vacuum pressure applied to the forming-box cavity below the lower diaphragm causes forming to take place. Polymeric diaphragms are commonly used due to their ability to deform without rupturing under high processing temperatures [2,3].

In-plane shear deformation is the dominant deformation mechanism used during formation of double-curved parts [4,5]. This deformation mechanism affects woven fabrics, warping the rotation of the yarns at their crossovers and causing a change in fiber orientation. The shear angle is the angle between the weft and warp yarns which indicates the quantity of the in-plane shear. Rotation around weave crossover is mainly limited by the ability of fiber yarns to contact each other (known as “locking angle”; see [6,7]). The locking angle occurs in woven fabric when the shear angle between the weft and warp yarns is locked and all yarns come into contact with each other and become compressed, causing a rapid increase in force that results in wrinkling [8]. Simulations conducted by Yu et al. [9] confirm the necessity of scaling up the in-plane shearing stiffness from what was measured in bias extension tests without compaction pressures in order to properly test this phenomenon. The present study implements compaction between two diaphragms during the bias extension test in order to understand the relative magnitude of in-plane shear stiffness under

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diaphragm forming conditions; these results can then be incorporated into bias extension test simulations.

The purpose of this study is to evaluate the magnitude of in-plane shear stiffness and shear angles under double-diaphragm vacuum compaction using a bias extension test. Changes in shear angle with respect to applied compaction forces are observed. In addition, the contribution of diaphragm compaction to shear stiffness is measured by comparing the results of the compaction test with results from a direct bias extension test.

2. Experimental setup

2.1. Materials

The out-of-autoclave prepreg selected for this study was the 8-harness satin woven carbon/epoxy from Cytec Engineered Materials. The resin code is (Cycom 5320) toughened epoxy and the fabric has 3K fibers per tow. The fabric areal weight is 375 g/m^2 and the resin content is 36% by weight. The measured thickness of uncured one-ply is approximately 0.47 mm. The diaphragm material used in this study was a translucent silicone rubber (EL1040T) manufactured by Torr Technologies Inc. (thickness 1.6 mm).

2.2. Bias extension test under diaphragms compaction

A bias extension test was conducted to study in-plane shear deformation under diaphragm forming compaction. Prepreg samples were placed between two diaphragm films; compaction was generated using a sealed vacuum bag due to the difficulty of sealing the two diaphragms together. Fig. 1 illustrates in detail the attachment of the prepreg sample and diaphragm films to the custom grips. The bias extension setup clamped in the tensile machine is shown in its entirety in Fig. 2. The load needed to extend the prepreg sample under diaphragm compaction can be described by the following formula [10].

$$F_s = F_t - F_d - F_f \tag{1}$$

In this equation, F_s is the load needed to extend the prepreg sample, F_t is the total measured load of the bias extension setup with the prepreg sample, F_d is the load required to extend the bias extension setup without the prepreg sample, and F_f is the friction

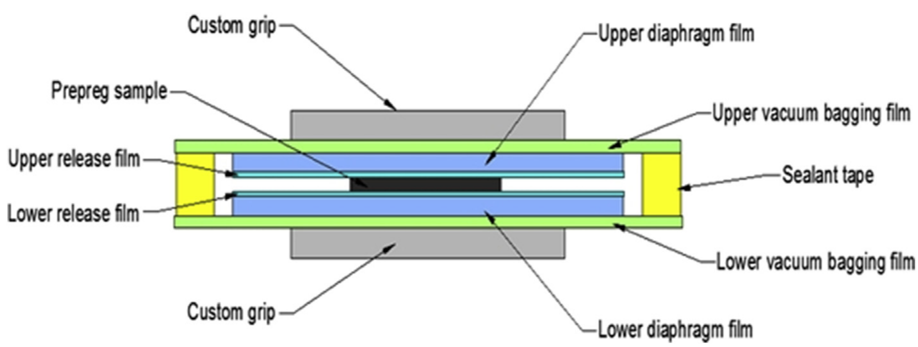

Fig. 1. Detailed diagram of attachment of prepreg sample and diaphragm films to the customs grips.

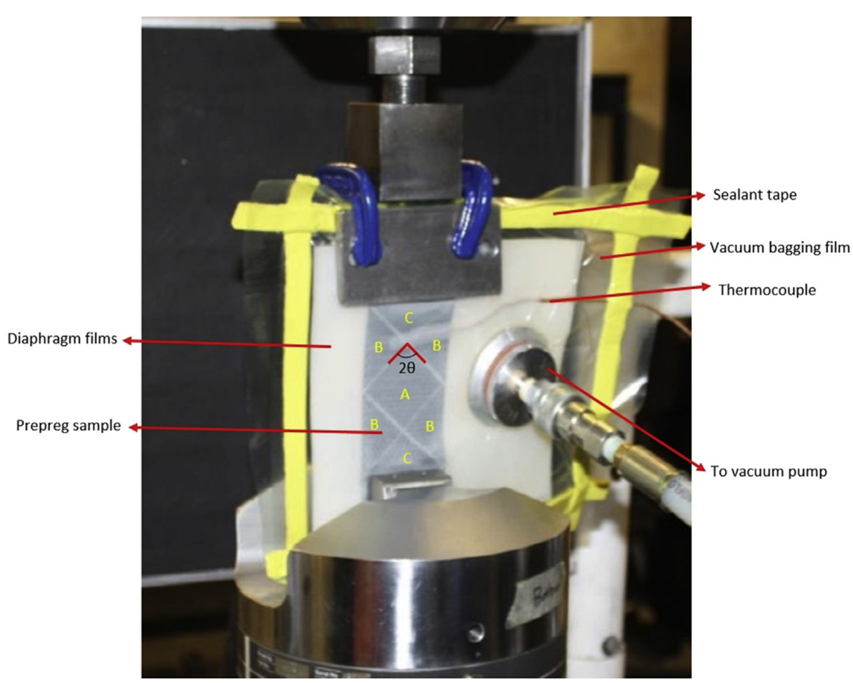

Fig. 2. Bias extension setup under diaphragm forming compaction.

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