
YOUJIANG WANG
School of Textile & Fiber Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0295, U.S.A.

(Received 20 July 2000; accepted 19 December 2000)

Abstract. This paper summarizes the consolidation behavior of E-glass stitched multiaxial non-crimp fabrics (NCFs) and the mechanical properties of the resulting composites from the manual layup process. NCFs offer many advantages over conventional woven and nonwoven fabrics in terms of processibility and properties. The reinforcement structures studied include six NCFs with different fiber orientation combination, number of sub-ply layers, and unit weight. The compressive and recovery behavior of the dry preforms is evaluated and related to their processibility in the hand lay-up process. Mechanical properties of specimens from the hand layup process are evaluated in tensile, compressive, and flexural tests. The test results and failure mechanisms are reported. The effect of consolidation quality on the mechanical properties is discussed.

Key words: failure, manual layup, mechanical properties, multiaxial warp knitted fabric, NCF, non-crimp fabric, stitched multiaxial fabric, testing, textile preform.

1. Introduction

Manufacturing cost represents a significant portion of the overall costs of composites, and textile technology has been turned to for manufacturing cost reduction [1, 2]. The multiaxial warp knit (MWK) process is a new development which offers another means of controlling the fiber architecture. The fabric structures consist typically of two to four layers of straight fiber strands held together by a chain or tricot stitch through the thickness [3–5]. The process involves arrangement of fiber layers followed by stitching [5]. The fibers in each layer can be oriented in the warp (0°), filling (90°), or a bias direction (typically between 30° to 60°). Unlike a woven fabric in which yarns are crimped due to interlacing, the multiaxial warp knitted fabrics preserve the unidirectional characteristics of each fiber layer. Such fabrics are also known as non-crimp fabrics (NCF). Figure 1 shows a typical NCF fabric. A nonwoven layer can also be incorporated into the fabric. Such fabrics are available with different fibers such as glass, carbon, aramid, or custom blends.

NCF fabrics have good dimensional stability that allows them to be handled easily in the composites manufacturing processes. The stitches allow relative fiber
movement in the fabric while at the same time maintaining uniform fiber spacing. The fabrics’ excellent conformability makes them suitable for making composite parts of complicated shapes (e.g. parts with double curvatures) without excessive cutting, joining, and post-consolidation machining. Since multiple fiber layers are handled in a single step, the composites manufacturing process is significantly simplified. The mechanical properties of the NCF composites, especially in compression, may be superior to those of conventional woven fabric composites due to the elimination of fiber crimp. A thin, textured polyester yarn is often used as the stitching yarn. A fabric’s dimensional stability and conformability can be altered by controlling the stitching yarn density or the stitching pattern. A high performance aramid or glass yarn may be used as the stitching yarn to improve the interlaminar properties and damage tolerance of the composites.

Composites with NCF can be made by processes such as traditional lamination, resin transfer molding (RTM), pultrusion, vacuum bagging, centrifugal casting, and filament tape winding. In addition to traditional composites applications, NCF composites are experiencing growth in such emerging markets as marine, sports, transportation, and infrastructure applications [6].

The literature on the mechanical properties of NCF composites is very limited. In an earlier study, the mechanical properties of NCF composites from the resin transfer molding process were evaluated [7]. Due to their close fiber packing and dense structures, reasonably high fiber volume fraction (about 50%) in the final composite part can be obtained even from the wet manual layup process. This