Recent Developments in 3D Woven Pi Preforms

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Introduction

• Jacquard weaving can be used to fabricate highly shaped fiber preforms
• Preforms used in a wide variety of aerospace engine and airframe applications
• Pi preform used in composite joints ribs or spar to skins
• Has been studied extensively and has demonstrated improved performance, cost, weight savings in co-cured or co-bonded joints
• Potential benefits have not been realised because:
  1. One size fits all
  2. Difficult to form
• Recent advancements have been made to address these problems
Electronic Jacquards enable Near Net Shape Weaving of Complex Shaped Components

- Individually controlled warp yarns
- Thousands of independent warp paths
- Servomotor controlled motions
- Increased design flexibility
3D Weaving uses Conventional Jacquard Technology in Unconventional Ways

Conventional Jacquard Weaving

- Complex In-Plane Patterns
- Weaver Friendly Fibers
- Non-Structural Applications

3D Weaving

- Complex Through-Thickness Patterns
- Aerospace Fibers (i.e. carbon)
- Structural Applications
3D Weaving can be used to Fabricate a Wide Range of Fiber Preforms

Contour Weaving

'Sock' Weaving

Near net Shape Weaving

Integrally Woven Structures
3D Woven Structures are Based on Bifurcating Multilayer Fabrics

Type 1
Continuous reinforcement across intersecting planes

Type 2

Type 3
Pi Preforms are Woven Flat and Folded into Shape

- Continuous fiber links upstanding legs to flange
- Tapered or uniform thickness legs
- Well suited to serial production
- $0^\circ$ fiber along length of preform (X or warp direction)
- $90^\circ$ fiber across width of preform (Y or weft direction)
- Z fiber in X-Z or Y-Z plane

As-woven $\pi$ preform

As-molded $\pi$ preform

Flange

Upstanding legs
Type 3 Bifurcations Provide Continuous Fibre Connecting Upstanding Legs to a Flange
3D Woven Inserts Improve Strength and Simplify Complex Composite Assemblies

- Double lap shear joint between web and flange
- Eliminates resin rich ‘noodle’
- Spreads loads at web/base intersection
Variable Cross Section Pi Preforms Have Been Fabricated

Variable thickness (0.10” – 0.40”)
Variable clevis width (0.125” – 0.750”)

Transition zone
Wide clevis
Narrow clevis
Variable Pi is Incorporated into a Large Preform that is Resin Transfer Molded

• Built up substructure
• Variable x-section Pi
• Multiple constant x-sections

Photo courtesy of Sikorsky
Pi Preforms can be Shaped by Shearing Planes of Weft Fiber

Columns of weft fiber remain parallel during forming.
Pi Preforms with Sine Wave

Sine wave web gives improved resistance to web buckling

- Flange formed to sine wave by shearing horizontally

- Web follows sine wave and caps straight

- Same process for variable width clevis applied

- Biased 2D fabric for web
Conclusions

• 3D woven Pi preforms can be tailored for specific applications to minimize weight without degrading performance

• Cross sections can be varied within a component
  • Flange width and/or thickness
  • Upstanding leg height and/or thickness
  • Clevis width

• Preforms woven with conventional fiber can be formed by shearing.

• By careful engineering preforms can be zoned to have regions that are more or less formable.

• Ability to directly weave complex shapes like sine wave pi.