Manufacturing and Design of Lightweight Composite Airplane Structures.

PART I - TECHNOLOGY

Prof. Eng. Giulio ROMEO – Dr. Eng. Giacomo FRULLA

POLITECNICO DI TORINO
(TURIN POLYTECHNIC UNIVERSITY),
Dept. of Aerospace Eng.; e-mail: romeo@polito.it
C. Duca degli Abruzzi 24, 10129 TURIN, Italy
Phone: +39.011564.6820 - Fax +39.011564-6899
Several military aircrafts, UAVs or business airplanes have been manufactured in these last twenty years by using advanced composite materials. Mainly because [Ref. 37, 39, 40]:

• Excellent physical & mechanical properties:
  - Low density - Very High Stiffness, Strength & Fatigue life along fibres direction.
  - Thermal expansion along fibres direction near to zero. - Resistance to corrosion.

• Significant weight saving can be achieved by using composites instead of aluminium alloys.

• Reduced part counts can be obtained with respect to metallic.

• A stealth concept can be better achieved because the radar absorbent material properties.

LIMITATIONS:

• Reduced allowables because of impact damage (in graphite composite)
• Reduced allowables in compression failure & transverse interlaminar stress (A-basis values).
• Environmental effects:
  - maximum operating temperature (in epoxy matrix) - moisture absorption (mainly in aramide composite) - damage through lightning strikes or erosion with metal (in graphite).
• Expensive Non Destructive Inspection method and Repair techniques. Costs.

• Mechanical properties are strongly directional;
• Good design knowledge is than necessary to better exploit these advantages.
The word composite describes a material where the interaction of two constituents (fibrous reinforcement + matrix) gives overall mechanical and physical properties of high efficiency. Filament diameter: Glass-Carbon-Aramid:6-10 microns; Boron:140-200microns. Form: tows/rovings (without twist) or yarn: bundles of several hundred thousand of filaments.

[Ref. 41]

Microscopic scanning of GRAPHITE/EPOXY

[Ref. 37, 39, 24]
Two main precursors are mainly used: 
PAN (Polyacrylonitrile: CH2 = CH-CN)n 
PITCH (from oil or coal) 

PAN-based: 
- First oxidation stage under stretch in air at 150-250°C 
- Carbonisation in nitrogen up to 1000-1500 °C or argon up to 2-3000°C 

Depending from the heat-treatment temperature and from the stretch level during the first oxidation stage, the tensile strength and tensile modulus of carbon or graphite fibres can have values very different for each type.

Five different groups of carbon fibres
- HS (High Strength) - VHS (Very High Strength) 
- IM (Intermediate Modulus) 
- HM (High Modulus) - VHM (Very High Modulus)
Manufacturing of Composite Structures

Aramid fibres (ARomatic polyAMID)
Made by Dupont or by Akzo from para or meta aramid

Boron fibres:
Reaction of hydrogen and boron trichloride at 1250°C. Deposition of boron on an electrically heated tungsten wire, at very low speed (2-3 m/s) up to 0.14-0.2 mm.

Glass fibres:
- Chemical structure of Silica (SiO2) + Oxides (Al2O3 & MgO)
- Made by drawing from the melt above 750°C, at very high speed (2-400 m/s).

Mechanical Properties of UD composite materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [Kg/dm³]</th>
<th>Young's Modulus [GPa]</th>
<th>Tensile Strength [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aramid/Epoxy</td>
<td>1.35</td>
<td>62</td>
<td>1600</td>
</tr>
<tr>
<td>Boron/Epoxy</td>
<td>2.10</td>
<td>240</td>
<td>1800</td>
</tr>
<tr>
<td>Carbon/Epoxy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UHM</td>
<td>1.80</td>
<td>415</td>
<td>1300</td>
</tr>
<tr>
<td>HM</td>
<td>1.65</td>
<td>240</td>
<td>1500</td>
</tr>
<tr>
<td>IM</td>
<td>1.60</td>
<td>180</td>
<td>2500</td>
</tr>
<tr>
<td>VHS</td>
<td>1.65</td>
<td>150</td>
<td>2200</td>
</tr>
<tr>
<td>HS</td>
<td>1.60</td>
<td>150</td>
<td>1500</td>
</tr>
<tr>
<td>Glass/Epoxy</td>
<td>2.05</td>
<td>50</td>
<td>2200</td>
</tr>
<tr>
<td>Aluminium Al</td>
<td>2.55-2.78</td>
<td>78-73</td>
<td>450-600</td>
</tr>
</tbody>
</table>

Volume fraction 60% (Aramid fibres: 50%)

[Ref. 37, 39, 40]
**EPOXY RESIN**: Thermosetting matrix. Reaction of epoxy group with hardener (diamine, dicyandiamided). No shrinkage, good bonding, chemically resistant. Limited ductility gives low damage tolerance, low hot/wet performances. As pre-preg (correct amount of resin, partially cured) has to be stored at -18°C. **OPERATING TEMPERATURE LIMIT**: 150°C

**BISMALEIMIDE RESIN**: Thermosetting matrix. Improved mechanical properties at higher temperature and under hot/wet conditions. **OPERATING TEMPERATURE LIMIT**: 230°C

**POLYIMIDE RESIN**: Very difficult preparation, handling & curing cycles (high volatile). **OPERATING TEMPERATURE LIMIT**: 315°C

**THERMOPLASTICS**: Better Damage tolerance performances, environmental resistance, fast processing. **OPERATING TEMPERATURE LIMIT**: 150°C

[Ref. 37, 39, 40]
Manufacturing of Composite Structures

Vacuum Bagging

Diameter = 1.5m; Length = 2m

[Ref. 27, 29, 31]
Manufacturing of Composite Structures

Tape winding or
Fibre placement

Filament winding
Manufacturing of Composite Structures

STAR SHIP

[Ref. 45]
Manufacturing of Composite Structures

THERMAL EXPANSION MOULDING TECHNOLOGY

[Ref. 28,29,33,38]
Manufacturing of Composite Structures

THERMAL EXPANSION
MOULDING TECHNOLOGY

Lockheed L-1011 Fin

Wing box

[Ref. 41,30,31,33]
Manufacturing of Composite Structures

HELIPLAT Tubular Technology

[Ref. 3,4,5,8]
Manufacturing of Composite Structures

HELIPLAT: CFRP Wing Box 21m Long

[Ref. 3,4,7,8,11]
Manufacturing of Composite Structures

CFRP WING BOX - 6m Long

[Ref. 11]
Manufacturing of Composite Structures

Truss Structure Technology

[Ref. 3,4,5,6,9]
Design of Composite Structures

Quadratic Failure Criterion:
\[ F_{ij} \sigma_i \sigma_j + F_i \sigma_i \leq 1 \]

C/E UD Brittle Tensile Failure

Fatigue behaviour

[Ref. 49]

MOISTURE ABSORPTION

[Ref. 42]
Design of Composite Structures

**MOISTURE ABSORPTION**

T = 70°C & 95%RH

**MOISTURE DESORPTION**

T = 60°C & Vacuum = 10^{-3} Pa

UD 0°

FABRIC 0/90°

[Ref. 18,23,49]
Design of Composite Structures

THERMAL EXPANSION TESTS

[Ref. 15,18,49]
Impact tests of carbon/epoxy at several impact energies

Residual Failure Load after Impact

Visible-damage threshold

Failure threshold

Kinetic Energy J

[Ref. 24]


