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Composite materials for primary aircraft structures: from development phase to high volume production rate

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Abstract:
From 1980's decade, the introduction of carbon composite materials in structural applications has been consistently increased in the successive generations of civil aircraft from Single Aisle to Middle-long Range to achieve a culminant point with more than 50% in structure weight in recent commercial civil aircraft. This evolution, done through successive iterations, has been possible by combining in the same time the improvement of intrinsic composite material performances and its transformation into prepreg production technologies together with the development of new manufacturing process for material lay-up automation at composite shop-floor manufacturer of aircraft composite parts. New challenges are still coming to continuously develop materials and technologies in order to pursue the production more cost-effective composite parts. Associated to higher aircraft production rate for single aisle, new challenges may force material and aircraft designers and producers to furthermore drive new products and processes introduction and new ways of transformation within in next decade of composite aircraft designs. We propose to illustrate these trends using past and recent developments and our return of experience from Hexcel on Civil Aircraft programs.

Keywords: composite materials; structural applications; prepreg technology; automatic lay-up processes; high production volume rate

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0 Introduction

Carbon-Fiber Reinforced Plastic (CFRP) material consists of a polymer employed as a matrix material in which carbon fibres with a diameter of a few micrometers are embedded. Different processes are used to manufacture semi-finished products and final products, depending on the geometry and requirement profile involved.

The use of CFRP components in the aviation industry is becoming more and more common. The knowledge in the use of Carbon Fibre Reinforced Plastic (CFRP) components is not new.

For example[1], Airbus has used carbon-fibre materials for years starting with the A310-200 in 1983 when the spoilers, airbrakes and rudders were made of sandwich CFRP. Three years later, the A310-300 pioneered the introduction of composite on a primary structure with the fin designed in monolithic CFRP. On the A320, carbon-fibre materials were used on flaps, ailerons, spoilers and on the vertical and horizontal tail plane. These developments were followed by large scale parts under complex loading such as the fuselage rear pressure bulkhead, keel beam and center wing box connected together the two wings.

Within this context of large introduction of carbon composites in structural part for civil aircraft (more than 50% in A350 XWB or in Boeing 787 structure

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weight), aircraft designers are working very closely with composite material manufacturers to ensure that mechanical performances are fully understood from initial phase of the qualification program, especially on a key point 'material deterioration and damage tolerance'.

1 Carbon Composite Materials' Development

During the past 20 years, the 180 ℃ cured epoxy resin systems, Which are most commonly used on structural epoxy/carbon composite parts have been progressively improved.

For the designers, it's well known that the main structural performances are obviously link to carbon fibre performances itself (From strength to stiffness), but performances and characteristics of epoxy matrix itself must be also taking into account specially if we consider the impact of aging and damage tolerance for final part design.

In this area three main axes from material supplier have been deeply concentrated to improve the intrinsic epoxy matrix performances by reducing progressively some detrimental effects:

1) Improve the intrinsic E modulus of epoxy resin to reduce drop of performance in compression mode (one of the most weakest point in composite design) in order to reduce buckling effect between matrix and fiber during compression loading.

2) Improve intrinsic toughness of epoxy matrix resin itself and reduce its sensitivity to damage tolerance and crack propagation[2-4] (moving from brittle to tough behavior).

3) Improve resistance towards water/humidity ingression in epoxy/carbon composite part to reduce the knock-down effect due to aging effect[5]. Even it has been demonstrated that this effect is reversible and are following typical Fick's Law[6] and Langmuir's[7] for water absorption behaviour, the reduction of sensitivity of epoxy matrix against water absorption are improving design criteria by giving more safety margin.

On the graphs in Fig. 2, we have highlighted the key evolutions of epoxy resin system which have been moved progressively from[8-10]:

1st Generation (1970-1980's) where "simple" epoxy resin + hardener have been used and exhibited good temperature resistance but were quite "brittle" material.

2nd Generation (1980-2000's) with epoxy + hardener + dissolved thermoplastic which improve intrinsic matrix toughness and reduce brittleness of overall composite material and improve the damage tolerance.

3rd Generation (2000's + onward) where on top of epoxy matrix, insoluble thermoplastic has been introduced to further increase the damage tolerance performance (by created a controlled interleave thermoplastic layer between ply layer in final composite laminate part) and also reducing furthermore the sensitivity to potential water ingression in final composite properties.

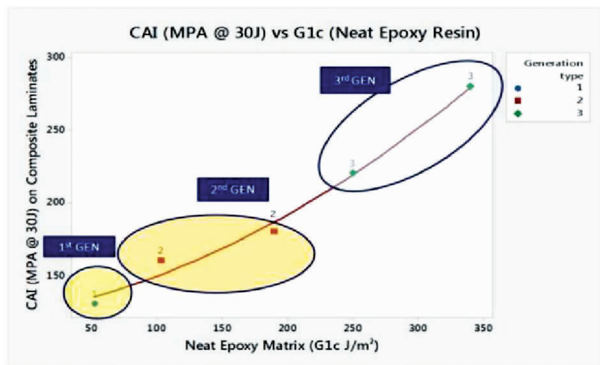

Fig. 1. Main evolution on materials from Generation 1, Generation 2 and Generation 3

As highlighted in above graphs, moving from epoxy matrix from 1st generation to 3rd generation, have brought following increasing performances on neat epoxy resin performances:

- ◆ E matrix modulus improvement
- ◆ Toughness improvement
- ◆ Water sensitivity reduction

Above achievements have been then directly translated into composite material performances part, specifically on aging after saturation level and hot/wet performances design, like static properties and un-notched and notched design values (OHT Open Hole Tension; FHT-Filled Hole Tension; OHC Open Hole Compression; FHC-Filled Hole Compression as per graphs below)

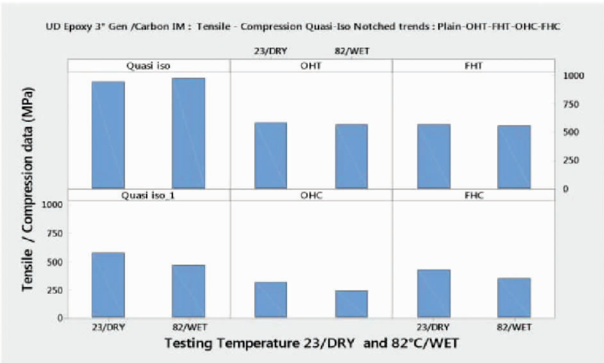

Fig. 2. Aging effect on hot/wet performances design for generation 3

Behind the material development, basically concentrated in the improvement of all constitutive elements from Carbon fiber (moving from High Strength (HS) to Intermediate Modulus (IM)), Epoxy matrix (generation 1, 2 to 3), compatibility and good translation of the tensile/compression performance through an optimized interface fiber/matrix, production technology has been also evolved to face with the challenge to manufacture composite material for high volume production rate needs. These challenges will be addressed in next chapter.

2 Process and Technology's Development

Together with material development described above, the process and technology from prepreg material production up to parts manufacturing in the end user shop-floor have significantly evolved over the past 20 years.

Starting initially from basic prepreg production process using mainly fabric (carbon, glass and aramid) combined with solvated epoxy resin in "tower" impregnation process that they were used by handlay-up in aircraft parts manufacture. Today most of composite parts produced are using a more controlled process using basically UD prepreg for laying-up the structural parts[11,12]. By using HS/IM carbon fiber associated with hot-melt 3rd generation epoxy (no solvent used) produced under continuous mixing and filming route a new generation of UD prepreg line have been developed.

The overall technologies deployed from PAN/Carbon Fiber to Resin-Film Continuous Mixing and Filming and last generation of Prepreg line fitted for large volume production have been able to achieve successfully:

- ◆ a very well resin content control on the final prepreg
- ◆ low cured ply thickness variability on final cured laminate/parts
- ◆ low tolerance on UD product width format for AFP machine deposition

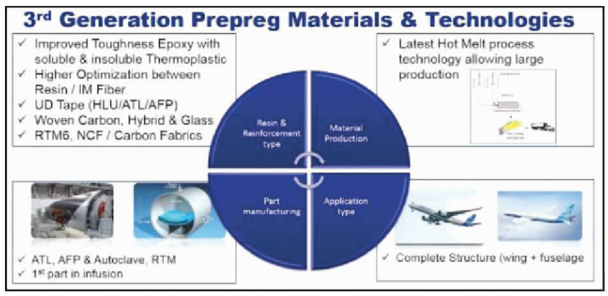

Fig. 3. Overall Technology of prepreg manufacturing for large volume production

In addition to secure the ramp-up and the volume needs (times x 50) as per initial 1980's demand), a dedicated supply chain model has been set up to concentrate the expertise on large volume productions and allow a more robust material flow done up to customer entry at point of delivery.

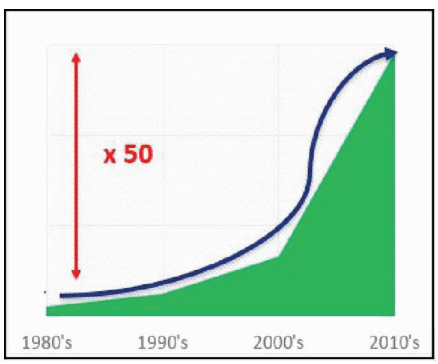

Fig. 4. UD carbon composite volume growth trends from last three decades

For this approach all the supply chains have been developed to have multiple production sites to ensure a good lead-time and robust quality. All the dedicated plants and production lines are using exactly same process/equipment (replica approach) and have been qualified as equivalent supplier by the end customers.

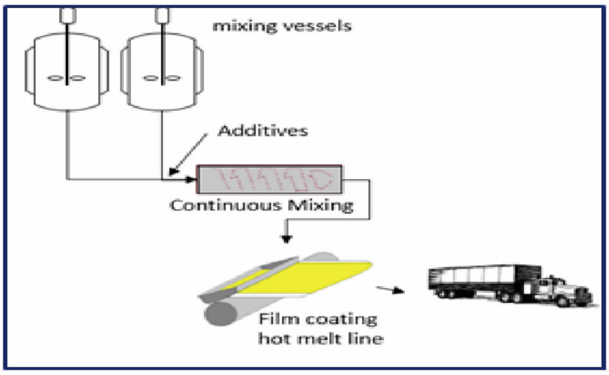

Fig. 5. Hexcel Internal supply chain developed for large volume carbon prepreg production

3 Conclusions

(1) A dedicated new generation of carbon/epoxy (called 3rd generation) of UD prepreg material has been developed to meet the challenges of composite material usage in structural civil aircraft.

(2) Dedicated processes and technologies with associated supply chains have been developed within Hexcel to ensure support to large volume needs of composite prepreg material, with high quality and good service level request for new generation of civil aircraft.

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