Composites Preforms Simulations for Helicopters Parts

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ABSTRACT: The performance of composite materials in structural aeronautical applications is routinely demonstrated. The structures of advanced helicopters mainly consist of Fibre Reinforced Plastics. Nowadays the huge majority of the structural parts is based on standard pre-preg design and manufacturing technology. In this study we present an alternative based on the preforming of a dry reinforcement and the infusion of this preform with resin. We've analysed the deformation modes of non-crimp fabrics which are used in those new processes. Behaviour during the variation of orientation of fibres (assimilated to in-plane shear) appears of utmost importance in order to study this performing. The defects which occur on real case are presented helping us to understand the mechanical behaviour of the material. We've then begun to set up a numerical simulation of the performing of a structural part for a helicopter.

1 INDUSTRIAL NEEDS

1.1 Hand Lay-Up of Pre-preg

Carbon fibre reinforced polymer composites (CFRP) are the state-of-the art of high-performance helicopter structures like airframes, empennage or rotor blades. The load carrying structures of Eurocopter's TIGER and NH90 products consist in app. 95% out of these high performance materials.

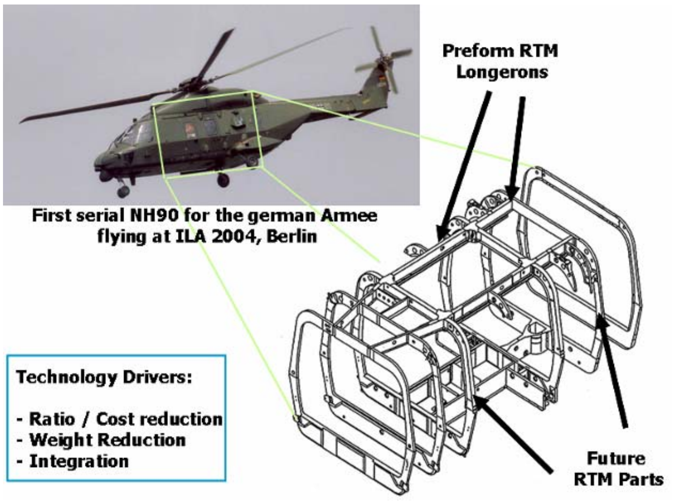


Fig. 1. Industrialisation of Preform/RTM parts in NH90

At the moment the huge majority of the structural parts is based on pre-preg designs and standard pre-preg manufacturing technology. They are processed conventionally out of Hand Lay-up and cured in autoclaves. The cost drivers are the hand-work, the use of autoclave and the quality control.

The future success of new helicopter programs is strongly dependant on the development of cost efficient manufacturing along with enhancement of concurrent engineering of complex and light CFRP parts. Those technology drivers are summed up in the figure 1.

1.2 New processes of helicopters parts

A promising type of process is the LCM (Liquid Composites Molding) such as RTM (Resin Transfer Moulding), or VAP (Vacuum Assisted Process). It provides possibly automation, out-of-autoclave curing and in-line-Quality. On top of that increased sizes of parts as well as higher volume production can be reached. They are based on resin impregnation of preforms. We are dealing here with the performing stage which is conditioning the whole quality of the part.

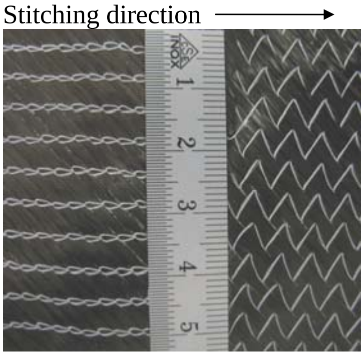
In a first step the materials have to be studied and their behaviour understood. In a second step, a simulation tool will be useful for the concurrent engineering [1] and the industrialisation of the process.

2 DRY TAILORED REINFORCEMENTS FOR PREFORMS

2.1 Preforming of dry Non-Crimp Fabrics

The preforming is the preparation and the forming of a temporarily product. This semi-finished product is dry, without resin. As a consequence, it's fragile, and need special handling, assembly and forming methods.
The reinforcement used in the study is a bi-diagonal carbon fibres non-crimp fabric (NCF), defined in the Table 1.

Table1. Definition of the NCF 'A' used in the study

Stitching direction → 	Type : NCF Loop Chain; HTS Fibers 12K, without Torsion. Linear Weight 400/450 tex Density (tow/mm) : $n_{warp/weft°}$=2,84 Stitching Pattern & Yarns: Loop Chain per 5mm Polyester (PES 48dtex) 4 g/m^2. Aeral densities(g/m^2) : $W_{warp°}$= $W_{weft°}$= 125 W_{NCF} = 254 Supplier : *Saertex GmbH*

The material has the specifity to be very thin, in order to fit the fineness in design required for the parts of helicopters (choice of the most optimal thickness).

2.2 Tailored Reinforcements & Intermediate Preforms

The preforms considered in this study are the so called Tailored Reinforcements (TR) made out of non-crimp Fabrics (NCF) which are sewed together [2]. The use of sewing allows a net-shape preforming (with variations in the thickness for example) and a better reproducibility.
The 2D-Preforming starts with a continuous lay-up of a multi-layer stacking sequence, which is considered as the basic module for specific designs. This basic element, which is cut to shape after the first fixation, is called the Tailored Reinforcement (TR) [2]. The fixation of the multi-layer stack is performed according to part requirements, e.g. individual stitching rows or local binder patches. For the concerned part we used stitching to achieve 2,5D semi-finished goods, the so-called "Intermediate Preforms" (IP), with strong variation of thickness. Finally, the 3D assembly of 3 IPs is performed. The process concludes with the compaction and ends with a net-shape cutting process.

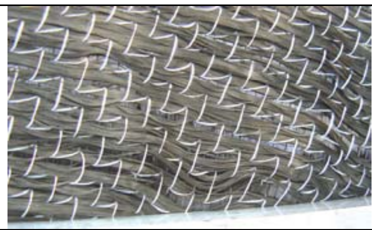
2.3 Defects during manufacturing of the preforms

In comparison to the pre-preg technology new types of defects appear during the manufacturing. The defects inherent to the material (fish-eyes, foozles) are not treated here. The defects inherent to the performing are listed bellow:

1. Waviness: planar sliding of fibres creating gaps between yarns or even planar waviness of a layer relative to another.
2. Fibre Pull-out: longitudinal sliding of fibres
3. Tear or break or loss of stitching yarns

They are presented and partially explained in the Table 2.

Table2. Main Defects depicted during preforming

Defect	Description	Cause & Consequences
1		Compression of counter fibres due to localised in-plane shear. Possible equivalence with wrinkles for woven.
2		Strong gradient in the path length of fibres. Implies the destruction of the fibre and its neighbours Implies change of orientation on the other layer.
3		Off-axis tension in stitching direction leading to threads pull out (Remark: we see the difference in the length of each direction)
3		Off-axis tension perpendicular to stitching direction leading to threads out-of-plane movements (lose of contact with fibres)

Those defects are linked to the special modes of deformation of the NCF.

3 IDENTIFICATION OF MECHANICAL BEHAVIOUR OF NCF

3.1 Tensile strengths

The tensile strengths in warp and weft directions correspond to the one of fibres as the NCF has no crimp. We've considered in the study the influence of the stitching on the tensile strength as negligible.

Table3. Tensile Strength

Direction	Stiffness	Strength
Warp	238 GPa	4300 MPa
Weft	238 GPa	4300 MPa

3.2 In-plane shear strength

The in-plane shear is the mode of deformation which is mandatory to form fibrous materials on a double curvature surface. A parameter is to be considered with the NCF: the behaviour +45° is different from the '-45°'. We tried to identify this stiffness with the 2 tests: Bias-Test and Picture Frame Test.

3.2.a Bias test

The bias test has been extensively presented, for instance in [3,4,5]. With woven fabrics a domain on the sample undergoes a pure shear state. With NCF reinforcements, the sample seems to lose its integrity early during the test. In the meantime the force measured remains constant and very weak. Subsequently we haven't considered any results from bias test on NCF.

3.2.b Picture Frame Test

This test consists in deforming an articulated frame under a tension at a corner while the opposite corner is clamped. A dry coupon is set in the frame with the fibres parallel to its edges. The fabrication of the sample includes the stitching threads so that the interaction threads/fibres (reported in Table 2) is taken into account.

3.3 Measurements

We've used the convention established in [3,4,5]

3.3.a Main curves

At the contrary to the curves obtained with woven fabrics, the curve is quite linear at the first iteration of the test of the specimen (figure 2).

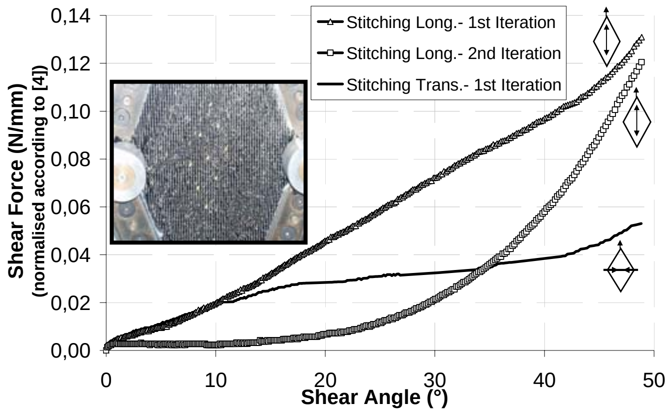


Fig.2. Trellis frame test with NCF 'A'

The mechanisms of deformation of an NCF during a trellis frame test are strongly different from those with woven materials [3,4].

3.3.b Influence of the number of test on a specimen

We tested the same sample twice. But at the contrary to Lomov & al. [4] we are considering here the first iteration of the test as decisive. The state of a new sample matches the state of the material before forming (i.e. contact between parallel fibres is not observed at the beginning of the 2nd iteration).

3.3.c Influence of the stitching

The results of trellis frame test on NCF are strongly dependant of the orientation of the stitching threads relative to the diagonals of the frame (cf figure 2). The stitching yarns placed longitudinally ('+45°') imply a higher reaction force from a shear angle of 10°. We should notice here that the whole normalised shear force is very weak, in comparison to equivalent woven fibres. That's why this parameter appears important to be identified.

3.3.d Conclusion on trellis frame test on NCF

The sample of NCF experiments during a picture frame test following deformation mechanism:

- Tension/compression of the stitching threads, not present for tests on woven fabric
- Rotation of the fibres
- Longitudinal in-plane compaction of the fibres
- Out-of-plane expansion of fibres [4]

All those deformations are not elastic. This test can be thus considered as an 'out-of-axis' tension/ compression test and not just as an identification test of the in-plane shear behaviour.
These mechanical characterisations have enabled us to quantify the behaviour of the material and provide input data to the process simulation.

4 FORMING SIMULATION

We conducted a simulation of the forming of dry NCF on the shape of a structural part of helicopter. The part type is a frame visible on the figure 1. It consists in 3 TRs (U,Z,L). The forming of the 'U' is the most problematic and will be simulated.

4.1 Simulation technique

Using the results of identification presented earlier (E_{warp}; E_{weft}, G with constant volume assumption), we implemented a model in PAMFORM (ESI). We used one layer MAT140 [6,7].

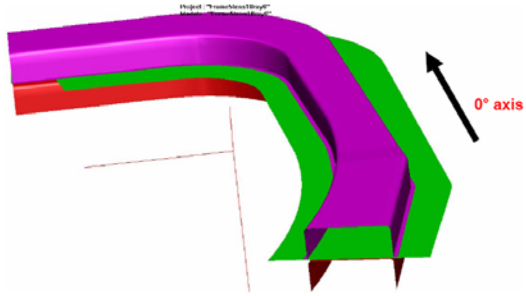
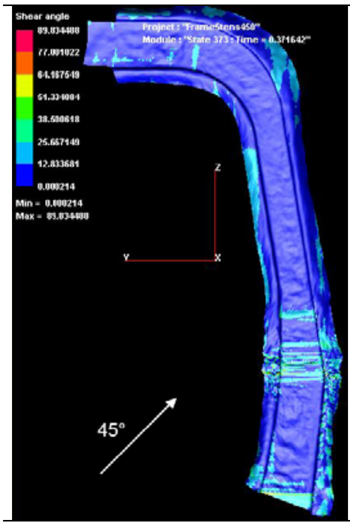
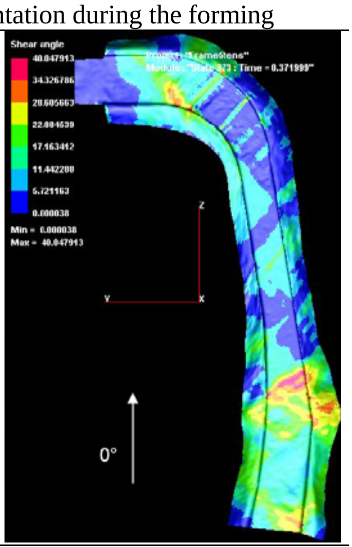


Fig. 3. Geometry of tooling and blank

4.2 Simulation of the forming of the part

The results are presented in the table 4. Two types of simulation are made depending on the original orientation of fibres.

Table4.: Variation of fibres orientation during the forming

	
+/- 45°	0/90°

At the same time step, we notice a lower variation of angles on the material +/-45° denoting a better formability. But this forming simulation implies to consider the material as continuous. The defect types 1 & 2 identified Table 2 won't be taken into account.

5 CONCLUSIONS

In order to improve the manufacturing of composites parts for helicopters, we analysed the deformation mechanism undergone by NCF reinforcements during a real forming case. In order to quantify them, the trellis frame test is satisfactory but not exhaustive. The forming simulation is promising, but need to be improved in order take all the defect criterion into account, to simulate the forming of several layers, and to shorten the time of calculation.

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