Towards the on-line qualification of carbon preforms produced by AFP

Together with Matrasur Composites, the Ecole des Mines de Douai (France) developed an Automated Fibre-Placement (AFP) system capable of producing carbon-fibre preforms directly from dry carbon tapes in order to avoid the use of prepregs and to reduce composite manufacturing costs in the aerospace industry. Within the framework of a research work in partnership with EADS and Aerolia, they identified a method to characterize fibre-placement quality during manufacturing.

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In the aerospace industry, composite manufacturing generally involves the use of prepregs or the infusion of non-crimp fabrics, which are both semi-products. To reduce costs, technologies capable of producing preforms ready to be infused, such as 3D woven or knitted structures, 3D braids or fibre placement, are currently being developed. The main advantage is that a 3D structure is obtained directly from a 1D raw material, the carbon-fibre yarn. It is then possible to achieve higher performance without being constrained by the 2D architecture of fibre mats, by taking into account the loads on the final part when designing the preform.

Dry fibre placement technology

Dry fibre placement technology is inspired by the filament winding process, which produces continuous-fibre components but is limited to structures with positive curvatures. An anthropomorphic robot equipped with a placement head was developed to produce preforms for complex-shape parts. The robot allows a flexible placement path and uses a compressive roller as a placement actuator to place the fibres. This technology takes advantage of the anisotropy of composites. It was developed for thermoset or thermoplastic pre-impregnated carbon-fibre tows or tapes. However, prepregs often involve high costs, because they need to be stored in a cold room to prevent premature polymerization and require local heating during the consolidation step. This tends to overcrowd the placement system, thus limiting part shape complexity.
To overcome these issues and meet cost and time efficiency requirements, recent developments focus on dry fibre-tow placement, using the dry fibre tow directly from the coil and placing it in the desired location and direction on a mould surface.
The Ecole des Mines de Douai and Matrasur Composites developed an automated placement head (see Figure 1) for the placement of complex-shape parts with, for instance, a double curvature or restrained access areas. The fibre coils are mounted above the placement head, moving along with it to allow complex placement paths. The fibre tows are unwound, engaged and cut automatically. Preform cohesion prior to the injection step is ensured by spraying a binder on the placement area. The binder will represent a few percent of the total preform mass and is chosen with respect to the type of resin used to manufacture the final composite part.

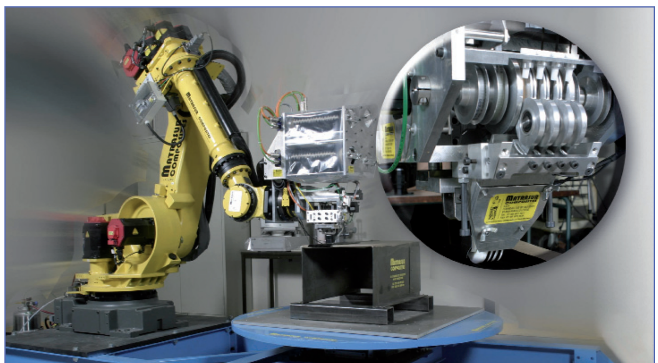

Fig. 1: Automated dry-carbon-fibre placement robot

On-line placement quality control

To enhance this set-up, the placement process can be controlled by a force cell fitted between the placement head and the robot arm. The set-up could prove more effective and less invasive than an on-line visual or optical control device. The following explains how it can help decide whether a preform is valid for manufacturing, or capable of providing the mechanical performance required for the final composite.

The potential of such a control device was explored by studying the mechanical behaviour of various placement patterns. The force cell fitted on the placement head can monitor the force variation response during the placement process to verify the local mechanical properties of the preform. For this purpose, a compression test is carried out on-line, providing information on the changing compliance of the preform and detecting process deviations from the ideal scenario. The advantage of this approach is that it considers the entire placement history of the whole preform, whereas visual control only gives information on the last-placed layer (provided that the contrast is sufficient).
The control methodology was calibrated by characterizing different fibre-placement patterns with a compression test prior to implementation in the robot programme. The preform compaction response is expected to change, which would indicate a different pattern or a placement problem. On-line visual control can be used as a complementary defect detection tool on an industrial device, or to clearly define the type of defect mechanically detected. The control actions required will be defined later, as they depend on the impact of the defect on the macroscopic properties of the preform, which implies another step in the current research programme.

Reference lay-up patterns

The first step in this development consists in obtaining preforms with different pattern types in terms of fibre-tow spacing. Three patterns are proposed, representing configurations that can be found in industrial preforms, such as local displacement of a fibre tow, either overlapping the neighbouring tow or creating a gap. The maximum displacement observed is about 2 mm. The first pattern, with regularly placed fibre tows, is the nominal pattern. The second one is the overlapping pattern, where one out of five fibre tows overlaps the preceding one by 2 mm. The third pattern is the open pattern, where one out of five fibre tows is at a 2-mm distance from the adjacent fibre tow.
The preforms are made of 8 layers oriented in different directions according to the defined stacking sequence [90,45,0,-45]s.
The preforms are produced automatically by the robot. The stacking sequence and spacing between the fibre tows are implemented in the robot software. The three reference preforms produced are presented in Figure 2.

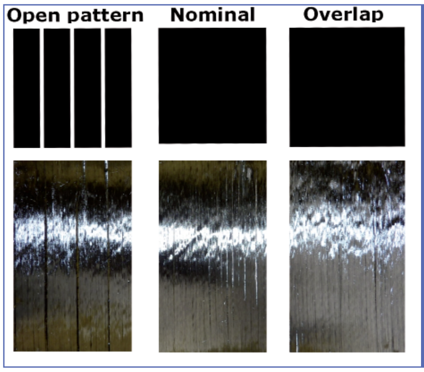

Fig. 2: Preform patterns designed and produced for reference

Mechanical identification of preform lay-up patterns

The preforms produced were mechanically tested with successive compressive tests simulating the application of new plies. The preforms were tested between two flat platens mounted on a Zwick compression test unit.
In a first step, the maximum fibre volume fraction that could be reached for each preform type was determined as a function of the load applied by the head and the roller radius. The load applied on each preform type and the fibre volume fraction derived from the preform thickness were monitored during the loading phase, as shown in Figure 3.

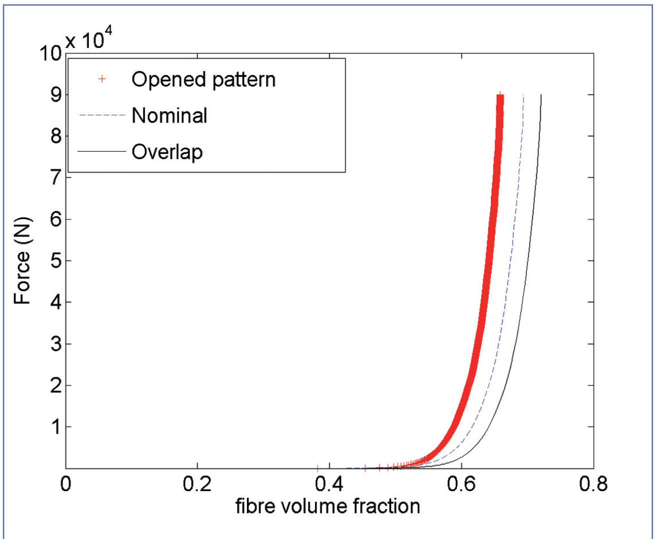

Fig. 3: Fibre volume fraction response as a function of the applied force

The preforms were loaded at a compression speed of 0.5 mm/min up to 90 kN. At a given load, the fibre volume fraction is lower for the samples cut from an open-pattern preform and higher for the overlap-pattern samples. The overlap pattern facilitates microstructural fibre arrangement when pressure is applied during fibre placement, resulting in a higher fibre volume fraction. Conversely, the open pattern retains gaps that are not filled during the compression process, reducing the fibre volume fraction.
Compressive cycle tests were conducted in a second step. Eight successive compressive loading and unloading cycles were performed on samples of the different preforms, representing the application of eight extra layers. The compression load was defined according to the contact surface with the fibre preform and the load applied during manufacturing. The parameter of interest is the evolution of the preform's plastic deformation that would represent a change in the preform thickness after one compression cycle. Figure 4 shows the evolution of plastic deformation after each compression cycle for all three preform types. For all three tested preforms, most of the plastic deformation was generated during the first compressive cycle. In the subsequent cycles, the additional plasticity per cycle remained small. The open preforms exhibited higher

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plastic deformation, due to the gap left between the fibres. The two other preforms (nominal and overlap) presented a similar plastic deformation. These results are encouraging, showing that the on-line control of fibre placement by monitoring the mechanical behaviour of the preform under local compression is feasible. Gaps between fibre tows can be detected through plasticity development, as the plasticity of the open-pattern preform is higher than the two other preform types. The overlap pattern, on the other hand, would be detected through a shift of the compaction curve towards higher fibre volume fractions.

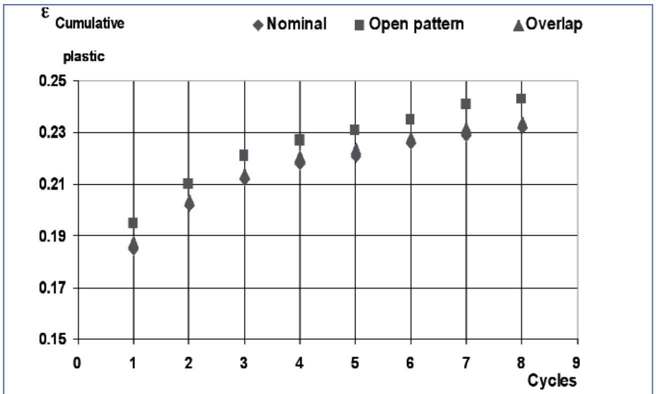

Fig. 4: Evolution of plastic deformation with the number of compression cycles

Towards on-line control

The technology changes implemented to reduce manufacturing costs lead to the development of new, reliable control devices. On-line mechanical monitoring is an easy, innovative way to control the preform structure produced. It was shown that the different laying patterns induce a change in the mechanical signature of the material. This change can be retrieved on-line in order to take corrective actions according to the final fibre volume fraction. The control steps required depend on the impact of the defect on the preform's macroscopic properties. This issue is also addressed in this research programme so as to link manufacturing tolerances to the composite's performance. ■

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